



# Computing Task Offloading and Processing for Power Internet of Things in Remote Areas

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**Abstract.** Power Internet of things (PIoT) is an important infrastructure to support the construction of smart grid. Remote areas such as grasslands and Gobi are important export places of power energy, and a large number of PIoT devices are scattered in these areas. The traditional terrestrial 5G network has high construction cost and relatively concentrated computing resources, which is not suitable for serving delay-sensitive and computationally complex intelligent PIoT tasks in remote areas. The satellite-terrestrial integrated network (STIN) and cloud-edge collaborative scheme for 6G provide a good idea to solve the above problems. In this paper, a 6G-oriented satellite-terrestrial cooperative integrated power IoT is constructed, which aims to support the Internet access of widely distributed PIoT devices in remote areas. A cloud-edge collaborative computing mode is proposed to meet the delay constraints and computational requirements of various artificial intelligence applications in the PIoT. In order to minimize the completion time cost of tasks, we formulate the optimization problem, and solve the optimal task offloading scheme by greedy algorithm. The experimental results show that the cloud-edge collaborative computing model shows good delay advantages and computing performance in the satellite-terrestrial integrated power Internet of things architecture.

**Keywords:** Power Internet of things · Satellite-terrestrial Integrated Network · Cloud-edge Collaboration · Task Offloading

## 1 Introduction

Power Internet of Things is a new product of the promotion and application of Internet of things (IoT) technology in smart grid, which effectively integrates communication and power system infrastructure resources [1]. Power plants, transmission lines, substations and other power infrastructure are gradually equipped with electronic eyes, sensors, 5G robots and other IoT devices to realize the rapid discovery, location and removal of faults. In 2018, more than 540 million smart electric meters and other terminals were connected to the State Grid, and the daily increase of collected data exceeded 60TB. It is expected that the number of access terminal devices will exceed 1 billion by 2025. These devices generate a large amount of video and sensory data all the time, which need to be

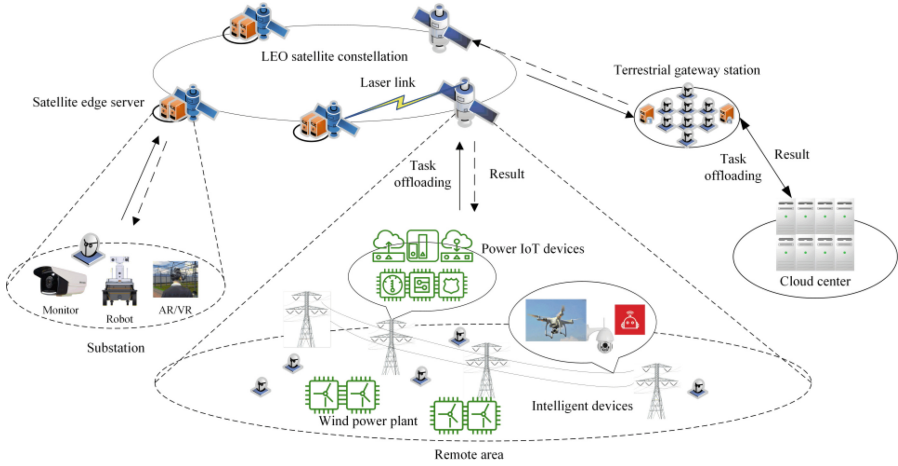
processed immediately [2]. On the one hand, smart grid communication systems require low latency and reliability. On the other hand, online real-time monitoring of transmission lines requires low energy consumption and real-time performance of data transmission. Obviously, traditional cloud computing cannot meet the needs of such business well, and cloud-edge collaborative intelligence technology can realize safe, agile, low-cost, low-latency, privacy-preserving artificial intelligence services and applications through the collaborative optimization between end, edge and cloud.

In particular, the vast expanse of grassland, Gobi and other areas are the main positions of wind power generation, often carrying the important function of electricity generation and transmission. Due to the large geographical span of the electric power infrastructure, the wide distribution of devices and the sparse population, the deployment of communication base stations in these areas is too costly and economically poor. The satellite network covers a wide area, and the LEO constellation composed of several low-earth orbit satellites can provide stable and continuous services for a certain area. In addition, the satellite can also act as a relay to transmit complex computing tasks through the ground station to the remote cloud for processing. Gao et al. [3] propose integrated satellite-terrestrial edge computing networks (STECN), aiming at minimizing the average response latency and average energy consumption by jointly selecting the optimal deployment of servers and services. Gong et al. [4] envision a two-layer satellite-terrestrial network model to minimize the total overhead in terms of energy consumption and latency for ground users. Long et al. [5] consider the combination of edge computing and cloud computing, and study the problem of task offloading with the optimization objectives of energy consumption, delay, and multi-node load balancing under an “End-Edge-Cloud” collaborative architecture for 6G network. Zhang et al. [6] present a cloud-edge collaborative computation offloading model that determines optimal offloading strategies and resource allocation based on task features. A joint latency and energy consumption optimization problem is formulated and described using the Markov decision process (MDP). In [7], a cloud-edge collaboration architecture including an offloading agent is presented, in which the agent assigns appropriate cloud or edge nodes to the tasks based on their characteristics. Although researchers have done some work in the field of satellite-terrestrial integrated network edge computing and cloud-edge collaboration respectively, they either ignore the deployment of cloud-edge collaboration in STIN to deal with complex computing tasks in remote areas, or ignore the strict requirements for task completion delay in PIoT scenarios. Therefore, for the task requirements of PIoT, this paper studies the satellite network assisted cloud-edge collaborative computing and task offloading in this scenario.

## 2 Satellite-Terrestrial Integrated Power Internet of Things

Power Internet of things aims to establish ubiquitous connection of equipment related to power, which has more terminals than the core power system, more information, and higher information security requirements. Because of its relatively high security and relatively low cost, the STIPIoT has become the preferred solution for the PIoT to solve the last mile access problem in remote areas. Power Internet of things in remote areas mainly involves overhead transmission line monitoring [8], transmission line UAV

inspection, cable and channel anti-intrusion alarm, substation video monitoring, substation robot intelligent inspection [9], remote real-time guidance for maintenance work, power data collection, environmental state collection, etc. Monitoring business generates a large number of delay-sensitive tasks, and tasks such as robot inspection and remote operation have stricter requirements on delay.



**Fig. 1.** Satellite-terrestrial integrated cloud-edge collaborative power Internet of things

As shown in Fig. 1, on-orbit edge computing capabilities are deployed on LEO satellites for STIIoT to provide instant edge computing services for PIIoT devices in remote areas through models trained by cloud centers. In LEO satellite constellation, edge computing servers are only suitable for deploying on some satellites, and satellites with on-orbit edge computing capabilities are called computing satellites. All satellites in the constellation have communication capabilities, but because they are always in motion, the computing request can only be received by the communication satellite that covers the area when the task is generated, which is called the receiving satellite. If the receiving satellite happens to be a computing satellite, the computing task will be processed immediately on the satellite. If not, it is forwarded to the idle computing satellite or cloud computing center for processing. If the computing resource requirement of the task exceeds the on-orbit edge computing capacity of the satellite, the computing task will be forwarded to the communication satellite covering the ground gateway station through the high-speed inter-satellite link, and then sent to the cloud center for computing processing. After the computation process is completed, the result is returned to the user by the communication satellite closest to the user. At the same time, the satellite edge cooperative nodes forward the computed results to the cloud data center through the ground gateway station to better train relevant models. The cloud data center returns the updated parameters to the satellite edge node to complete the update of the system.

### 3 Cloud-Edge Collaborative Task Computing Model

In this system, we assume that each PIoT device generates a computing task request in a time slot, and each satellite edge computing node can serve multiple PIoT devices. Let  $N$  denotes PIoT devices, that is  $N = \{ 1, 2, \dots, n \}$ ,  $M$  denotes satellites in the LEO satellite constellation, that is  $M = \{ 1, 2, \dots, m \}$ . Let  $D_i$  be the upload data volume of the computing task  $i$ , the size of the computed results is  $\alpha$  times the size of uploaded data. The bandwidth of the satellite-terrestrial transmission link is recorded as  $B_{sg}$ , the high-speed inter-satellite laser link rate is  $R_{ss}$ , then the transmission delay of the  $i$  th task processed at the  $j$  th satellite edge node can be expressed as

$$T_{tr}^e = (1 + \alpha) \frac{D_i}{B_{sg}} + m_j \times (1 + \alpha) \frac{D_i}{R_{ss}} \quad (1)$$

if the  $j$  th satellite is a computing satellite,  $m_j = 0$ ; Otherwise,  $m_j = 1$ .

The transmission delay of the  $i$  th task processed at the ground cloud center can be expressed as

$$T_{tr}^c = (1 + \alpha) \left( \frac{2D_i}{B_{sg}} + \frac{D_i}{R_{ss}} \right) \quad (2)$$

The height of the satellite is denoted as  $h$ , the distance between the satellites is  $d_{ss}$ , and the signal propagation speed is equal to the speed of light  $v$ . Then the propagation delay of the  $i$  th task processed at the  $j$  th satellite edge node can be expressed as

$$T_{pro}^e = \frac{2(h + m_j \times d_{ss})}{v} \quad (3)$$

The propagation delay of the  $i$  th task processed at the ground cloud center can be expressed as

$$T_{pro}^c = \frac{4h + 2d_{ss}}{v} \quad (4)$$

Let  $\eta_s$ ,  $\eta_c$ , represent the volume of data that can be calculated per second by the satellite edge node and the cloud computing center, respectively. Then, the computation delay of the  $i$  th task can be expressed as

$$T_{com}^e = \frac{D_i}{\eta_s} \quad (5)$$

$$T_{com}^c = \frac{D_i}{\eta_c} \quad (6)$$

In summary, we calculate the total time cost of completing the  $i$  th PIoT computing task as

$$T_{cost}^i = \theta \left( T_{tr}^e + T_{pro}^e + T_{com}^e \right) + (1 - \theta) \left( T_{tr}^c + T_{pro}^c + T_{com}^c \right) \quad (7)$$

where, when the task is processed at the satellite edge node,  $\theta = 1$ , otherwise,  $\theta = 0$ . In this paper, we minimize the total completion time of these tasks in system. The minimization problem is formulated as

$$\min_{\theta} T_{total} = \sum_{i=1}^n T_{cost}^i \quad (8)$$

*s.t.*  $\alpha \in (0, 1)$

As show in **Algorithm 1**, a greedy algorithm is proposed to solve the problem. With the minimum time cost as the optimization objective, when solving the scheduling policy, only the local optimal policy  $R_i$  for processing a certain task in the current state is considered.

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**Algorithm 1.** Greedy Algorithm

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**Input:**  $D_n, B_{sg}, R_{ss}, h, d_{ss}, v, \eta_s, \eta_c$ .  
**Initialize:** Set  $N$ .  
**While**  $N < n$  **do**  
     Compute  $T_{tr}^e, T_{pro}^e, T_{com}^e, T_{tr}^c, T_{pro}^c, T_{com}^c$ .  
      $T_{cost}^e \leftarrow T_{tr}^e + T_{pro}^e + T_{com}^e$   
      $T_{cost}^c \leftarrow T_{tr}^c + T_{pro}^c + T_{com}^c$   
     **If**  $T_{cost}^e < T_{cost}^c$ , **then**  $\theta = 1$   
     **else**  $\theta = 0$   
     **end if**  
      $N \leftarrow N + 1$   
**End while**  
**Output:**  $\theta_n$

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## 4 Experimental Result

The power line image anomaly detection model service is selected as the experimental object of the cloud-edge collaborative computing strategy. The experiments used a powerful server emulation cloud-centric server, with Intel(R) Core(TM) i7-6700HQ CPU, 8 GB RAM, and  $1 \times$  NVIDIA A100 40 G GPU. The NVIDIA Jetson TX2 was used to simulate the satellite edge server with  $4 \times$  Quad ARM A57 CPU and 8GB of memory. The experimental scenario is set in a remote area with an area of 100 square kilometers, and the satellite network simulates a similar walker constellation with 40 LEO satellites distributed in five orbital planes.

In order to simulate the load situation of computing tasks in PloT, we tested for different number  $N$  of PloT devices,  $N = 100, 225, 400$ . The data size of each power image recognition task is uniformly distributed in [100M, 400M]. The experiment uses three processing methods for comparative analysis: cloud only, edge only, and edge-cloud cooperation. Table 1 shows the task completion time for different configurations. From the results in Table 1, we can see that when  $N = 400$  and 100, we transfer 93.8% and 34.7% of the data to the cloud, respectively. The execution time of the edge-cloud

cooperative scheduling strategy is reduced by 3.25% and 73.56% respectively than that executed only in the cloud center, and about 30.06% and 29.28% respectively than that executed only in the edge server. It is worth mentioning that when  $N = 300$ , we transfer 79.23% of the data to the cloud. Compared with executing only in the cloud center, the execution time of the edge-cloud cooperative scheduling strategy is reduced by 26.66%. Compared to executing only on the edge server, the execution time increases by 3.71%. This is because the greedy algorithm to solve the model is a locally optimal solution and there are still problems such as estimation errors.

## 5 Conclusion

The satellite-terrestrial integrated network and cloud-edge collaborative computing mode provide a good solution to support delay-sensitive and computationally complex tasks of PloT in remote areas. In this paper, the satellite-terrestrial integrated power Internet of things is constructed and a cloud-edge collaborative computing mode is proposed to meet the delay and computing requirements of various artificial intelligence applications in PloT. In this paper, the optimization problem formulation is established to minimize the time cost of task completion, and the best task offloading scheme is solved by greedy algorithm. The experimental results show that when the number of devices in the STIoT is large, the cloud-edge collaborative computation mode shows good delay and computational performance. In the future, the computing scheme of end-edge-cloud collaboration in the STIoT will be our research idea to solve large-scale delay-sensitive tasks and computation-intensive tasks. The assistance of unmanned aerial vehicle will also be the key directions to consider in the future research on the integrated satellite-aircraft-terrestrial power Internet of things.

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