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Optimal replication strategy for mitigating burst traffic in information-centric satellite networks: a focus on remote sensing image transmission

Key words: Information-centric satellite network; Burst traffic; Content delivery; Federated reinforcement learning; Mixed-integer linear programming model; Bloom filter; Dynamic network

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Motivation

- Information-centric satellite networks play a crucial role in remote sensing applications, particularly in the transmission of remote sensing images. However, the occurrence of burst traffic poses significant challenges in meeting the increased bandwidth demands. Traditional content delivery networks are ill-equipped to handle such bursts due to their pre-deployed content.
- The research motivations are to fully use the spatiotemporal properties of remote sensing images in the information-centric satellite network and to solve the problem of content delivery in a burst traffic scenario.

Main idea

- We propose an optimal replication strategy for mitigating burst traffic in information-centric satellite networks, specifically focusing on the transmission of remote sensing data. By selecting the most suitable replication delivery satellite node when multiple users subscribe to the same remote sensing content within a short time frame, we effectively reduce network transmission data and prevent throughput degradation caused by burst traffic expansion.
- We formulate the content delivery process as a multi-objective optimization problem and apply Markov decision processes to determine the optimal value for burst traffic reduction. Leveraging federated reinforcement learning techniques, we address the challenges posed by burst traffic in information-centric satellite networks.

Framework

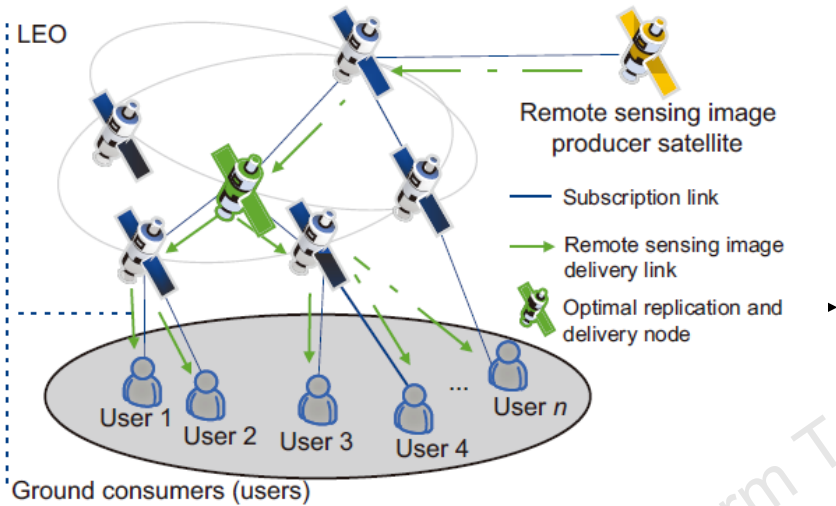


Fig. 2 Scheme of a satellite delivering remote sensing images to multiple users on the ground (LEO: low Earth orbit)

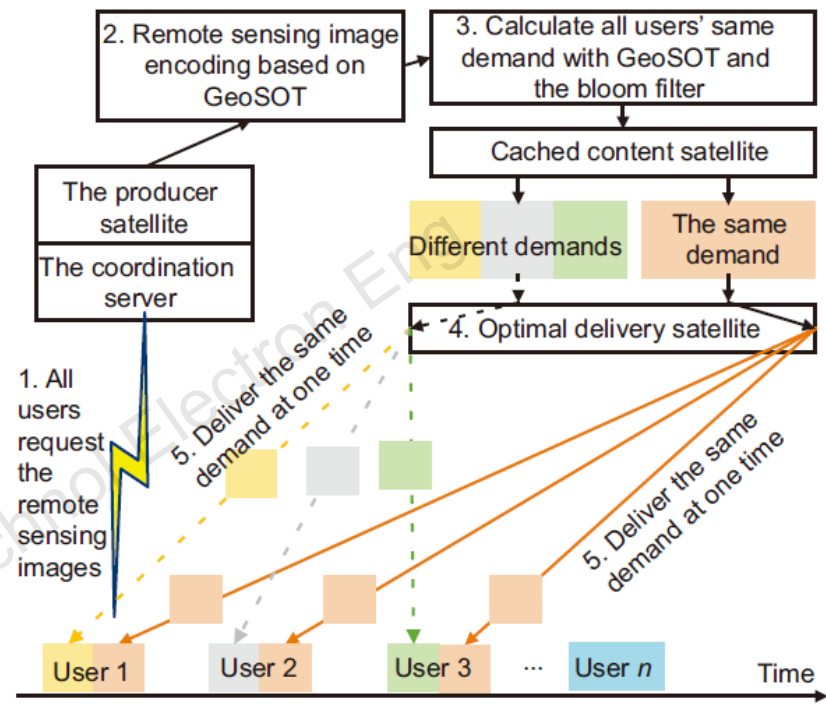


Fig. 4 Principle of avoiding burst traffic and its relationship with each section

1. All users request remote sensing images. 2. The producer satellite performs GeoSOT encoding on the remote sensing. 3. The producer satellite calculates the same and different requirements from the cached satellite nodes based on GeoSOT and the bloom filter. 4. The producer satellite calculates the optimal delivery satellite node and delivers the remote sensing images to all users through the optimal satellite delivery node. 5. The same demand requires only one copy, while different remote sensing images are delivered separately to users one by one.

Method

The algorithm first sorts the nodes of all disjoint graphs by the weight, and if the vertices of the edges belong to two disjoint sets, they will be merged into one group.

The content delivery problem can be expressed as follows:

$$P \|n_b, d_{w_s}\| = \min (H (n_b, n_{b+1}) + P (n_{b+1}, d_{w_s})) .$$

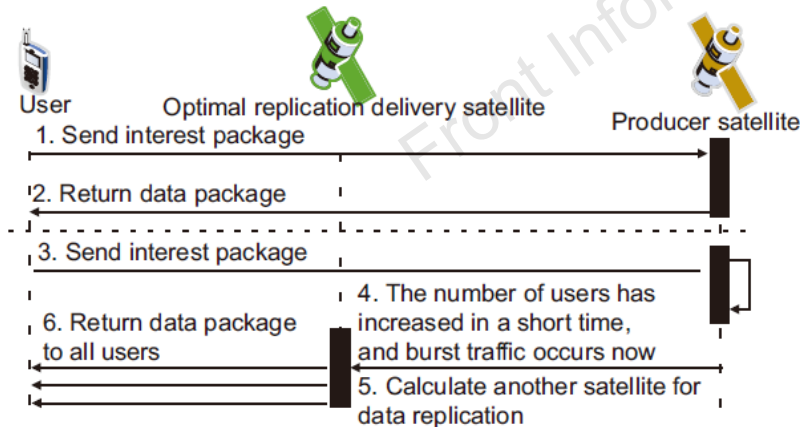


Fig. 5 The content delivery process of the satellite network (the number of ground users has increased in a short time)

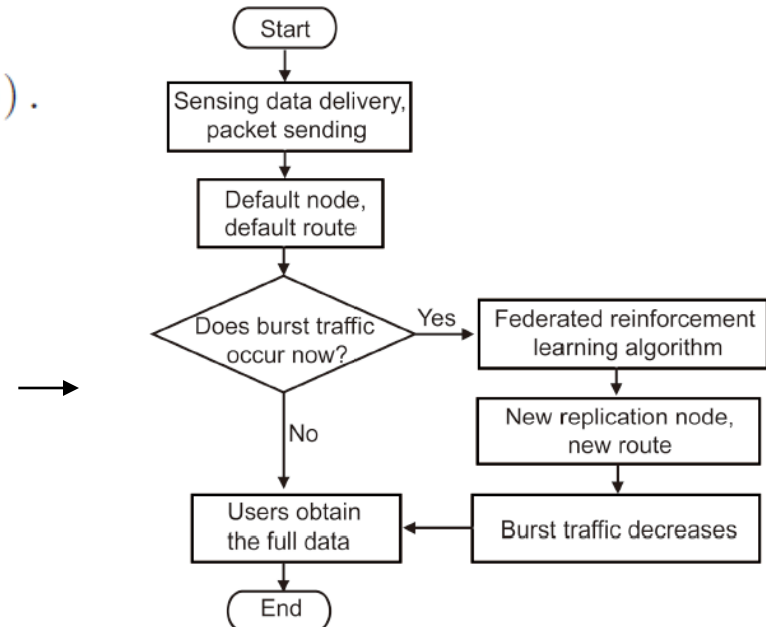


Fig. 6 Flowchart of data flow transmission

Method

The goal is to reduce data caused by unsuitable nodes and to increase the consumption of resources.

Finding the optimal replication nodes is the key.

We solve the multi-objective optimization through federated reinforcement learning to obtain the optimal replication delivery node.

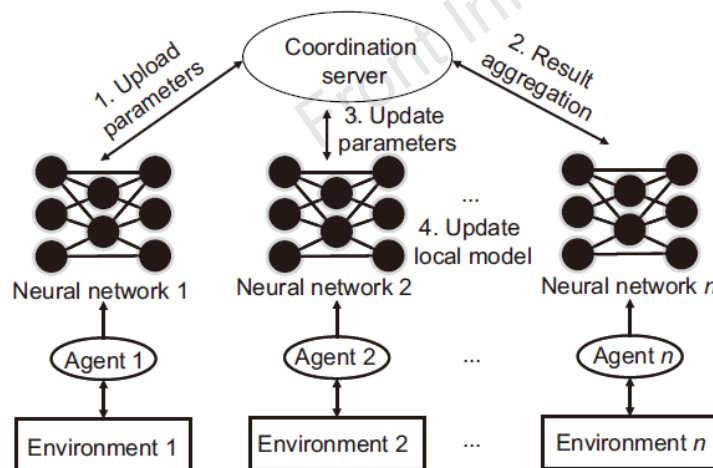


Fig. 7 Federated reinforcement learning model

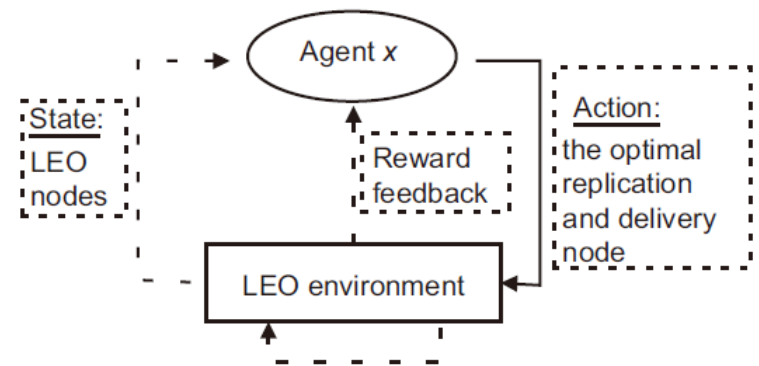


Fig. 8 Interaction between multiple agents and the environment in a satellite network (LEO: low Earth orbit)

Conclusions

Information-centric network (ICN) is an important direction in future network architectures, and efficient transmission is achieved by decoupling location and content. Aiming at the drawback of performance degradation with the increase in the number of users during content delivery for traditional satellite networks, we use federated reinforcement learning to generate an optimal replication delivery satellite node, which effectively reduces network transmission data and avoids burst traffic.

It can easily cope with the impact of a sudden surge of users on the delivery of remote sensing images.



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