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Adaptive multi-layer deployment for a digital-twin-empowered satellite-terrestrial integrated network

Key words: Digital twin; Satellite-terrestrial integrated network; Deployment; Multi-agent reinforcement learning

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Motivation

Satellite-terrestrial integrated networks (STINs) aim at global seamless communication coverage but face challenges in dynamic resource allocation due to network dynamics, resource heterogeneity, and user mobility. Digital twin (DT) technology can map a physical network to a virtual one for monitoring, analysis, and optimization. However, the deployment and resource allocation of DTs can impact their performance.

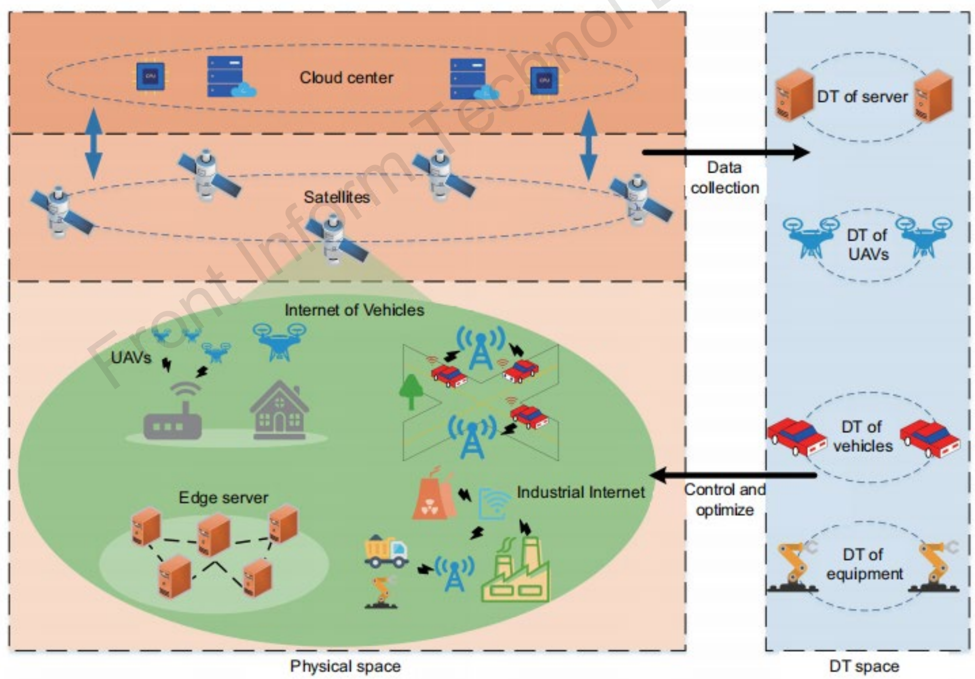

Fig. 1 DT network architecture of a satellite-terrestrial-integrated network (UAVs: unmanned aerial vehicles; DT: digital twin)

Main idea

- To address the challenges of deploying DTs in the network, we innovatively formulate the DT multi-layer deployment problem in a STIN to reduce system delay, ensure the interaction between users and DTs, and improve the user experience of DT services.
- We propose an algorithm based on multi-agent reinforcement learning (MARL) that formulaically solves the proposed DT deployment problem by considering the DT deployment strategy and system delay. Ultimately, the simulation results substantiate the efficacy of the proposed algorithm.

Method

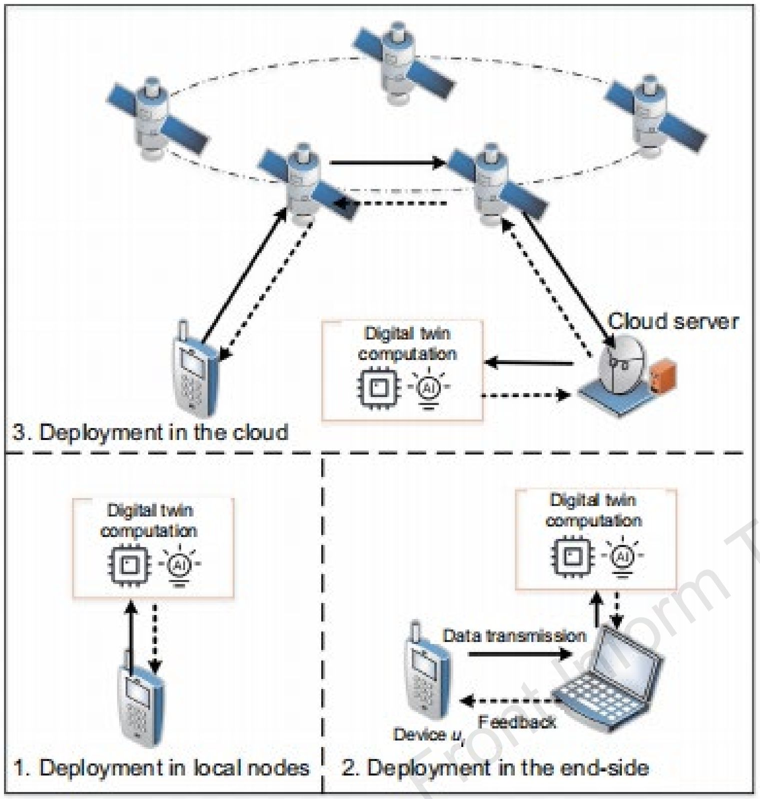

Fig. 2 Process of constructing a digital twin model

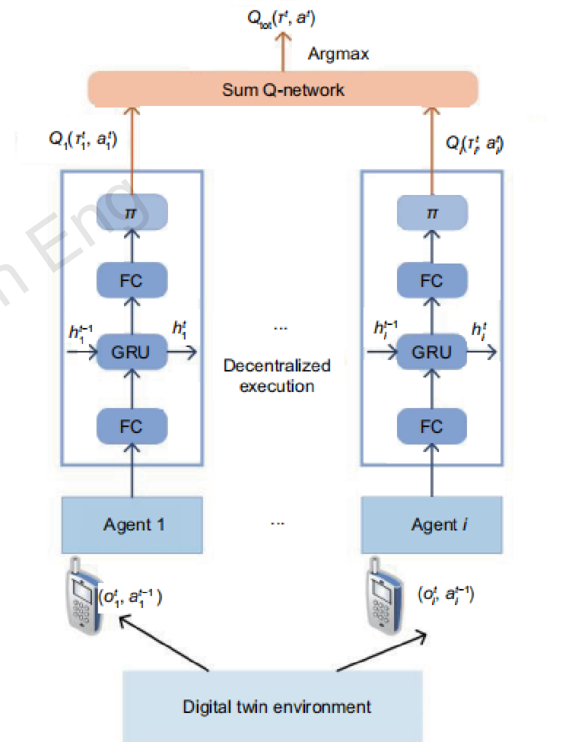

Fig. 3 The MARL method for the DT deployment structure (MARL: multi-agent reinforcement learning; DT: digital twin; GRU: gate recurrent unit; FC: fully connected)

Deployment in local nodes: limited computing resource and no communication delay.
Deployment in the end-sides: ample computing resources and low communication latency.
Deployment in the cloud: abundant computing resources and high communication latency.

Results

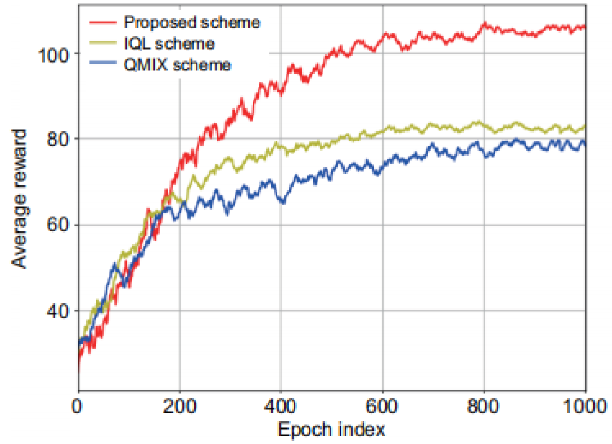

Fig. 4 Average reward

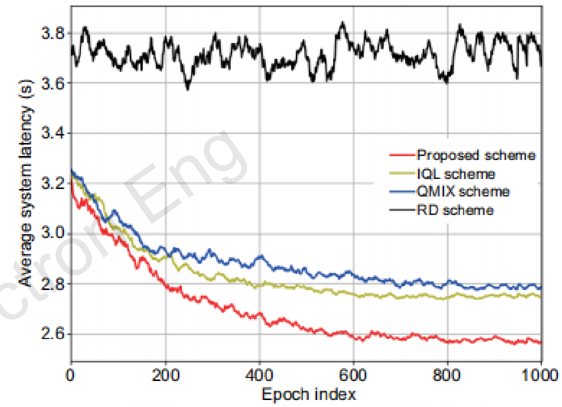

Fig. 5 Number of epoch rounds vs average system latency for different algorithms

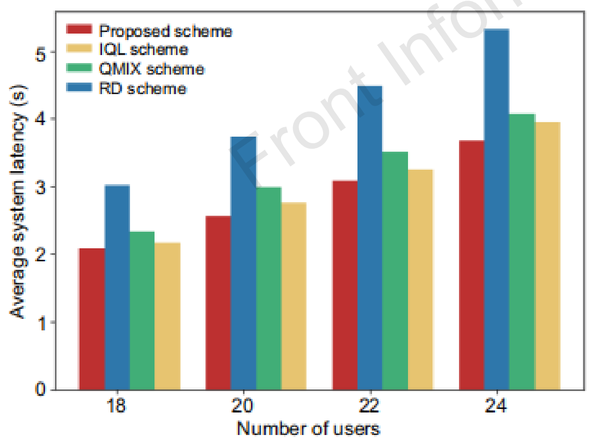

Fig. 6 Number of users vs average system latency for different algorithms

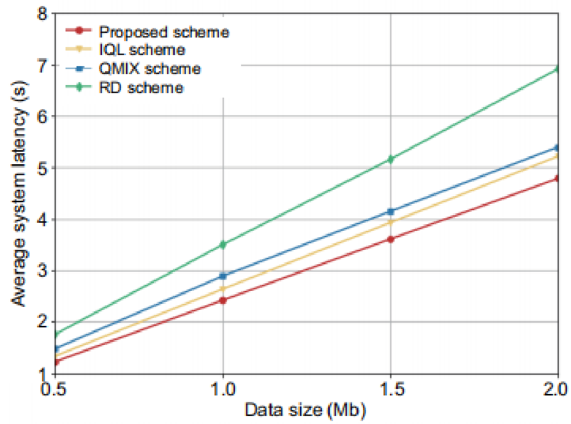

Fig. 7 Data size vs average system latency for different algorithms

Conclusions

In this paper, we innovatively formulate the DT multi-layer deployment problem in a STIN to reduce system delay and ensure the interaction between users and DTs. We employ an MARL algorithm to address the multi-layer deployment challenge. Simulations confirm that our approach significantly reduces system latency.

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