Learning through the Air: Cross-Layer UAV Orchestration for Online Federated Optimization

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https://sites.google.com/view/nsf-ccpls

Challenge:

How can we ensure the effective operation of Collaborative Cyber-Physical Learning Systems (CCPLSs) despite the challenges posed by large-scale, high-dimensional, heterogeneous, and dynamically evolving datasets?

Solution 1: Communication, Resource and Training Efficient FL

Key Problem: How to make FL systems efficient for real-world deployments?

❖ **Autoencoder-Based AirComp for Wireless FL**

- Bridges the gap between **modern wireless digital systems and analog AirComp**
- Proposes an **autoencoder-based digital modulation** for FL aggregation
- Results in accurate sum signal decoding

❖ **Hierarchical Independent Submodel Training (HIST) for FL**

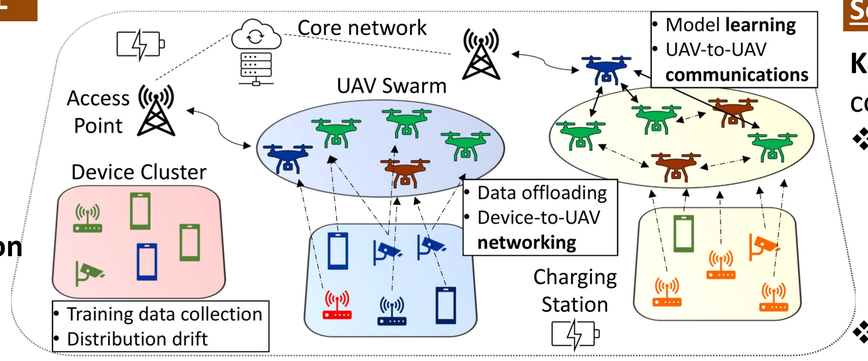
- Addresses issues regarding **computation, communication and storage** in HFL systems
- **Partitions global models into disjoint submodels**, reducing per-device training cost

❖ **SD-GT: Semi-Decentralized FL with Gradient Correction**

- Solves **statistical heterogeneity** problem across devices
- Introduces **gradient correction** to resolve **intra and inter cluster heterogeneity**

❖ **GCN-Optimized Device Sampling**

- Uses **Graph Neural Networks (GCN)** to optimize device selection and **D2D offloading**
- **Device sampling** must consider **D2D offloading** opportunities



Solution 3: Fairness & Personalization in FL

Key Problem: How to ensure fairness and personalization in FL models?

❖ **Equitable FL via Activation Clustering:**

- Utilizes **activation vectors** to ensure fair treatment across client clusters
- Ensures group fairness by **reducing variance** in test accuracy across clients

❖ **FedACS (Attention-Based Client Selection):**

- Addresses **model personalization** under **non-IID** data distribution
- Dynamically **prioritizes important clients** to enhance training

Solution 2: Advances in Optimization and Convergence Analysis

Key Problem: Designing optimization methods with improved convergence guarantees and theoretical robustness?

❖ **FESS-GDA:**

- **Federated minimax optimization** method using **stochastic smoothed gradient descent ascent**
- Achieves **better sample and communication complexity** compared to existing methods

❖ **Primal-Dual Optimization(PPALA):**

- Developed an **efficient primal-dual method** to find **approximate stationary solutions** with **performance guarantees**
- Ensures solutions satisfy ϵ**-KKT conditions**, improving optimization efficiency for constrained non-convex problems

Broader Impact:

❖ *D*evelopment of UAV-assisted CCPLS for a variety of application domains, manufacturing of UAVs and other unmanned vehicles tailored for CCPLS

❖ *Research dissemination and curriculum development:* Develop new course modules for the courses taught by the PIs, e.g., **Optimization for DL, Wireless Communications, Communication Networks**. A **postdoc** supported by this project **started as a faculty in August 2024**

❖ *Outreach and community engagement:* Advising **VIP team** working on **multi-robot teams**, an instance of CCPLS

Scientific Impact:

Immediate application in smart and connected agriculture in remote areas, but theory, algorithms, and foundation broadly applicable. Advances in optimization algorithms ensure stable, scalable, and theoretically grounded solutions for FL.

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