xGFabric: Coupling Sensor Networks and HPC Facilities with 5G Wireless Networks for Real-Time Digital Agriculture

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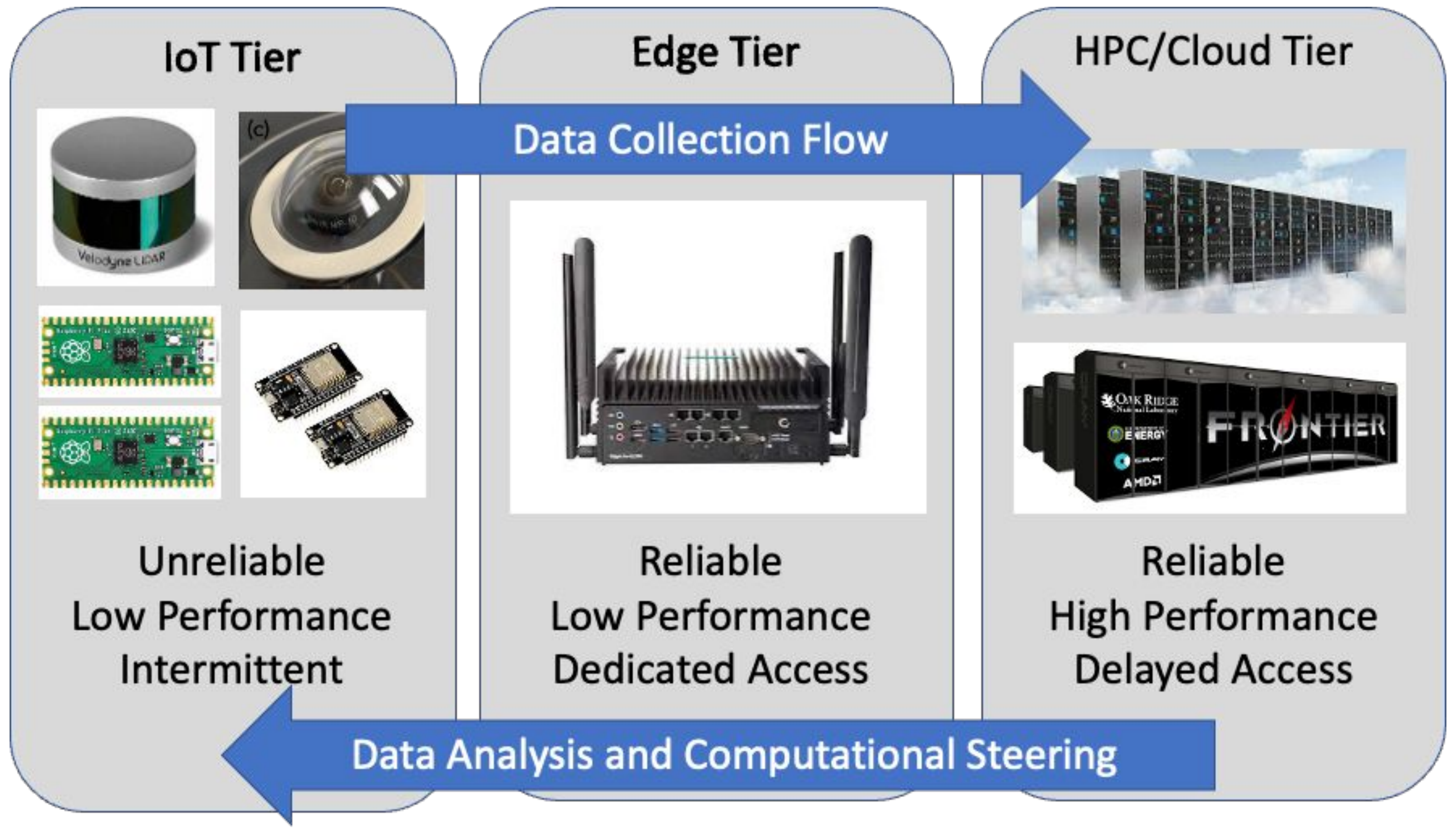
Abstract

Our objective is to design and evaluate an **end-to-end, multi-scale, adaptive system**—**xGFabric**—that unifies leadership-class **HPC resources** with **sensors, instruments, and actuators** through a tiered computational and storage network. **xGFabric** leverages **5G/6G** technologies to integrate computing, storage, sensing, and actuation across scales using new abstractions, programming models, and middleware. Rather than integrating disparate technologies, we study xGFabric as a cohesive platform with integrated HPC support and distributed workflow management. **Advanced wireless digital agriculture** serves as our science driver, with prototypes validated on field testbeds at the University of Nebraska-Lincoln and the University of California. Building on our prior research in 5G/6G, IoT, and multi-messenger astronomy, we will develop **sensor virtualization** for **network slicing** and release a full-stack, multiscale platform as **open-source artifacts**.

Tools

6G RAN	Wireless Radio Access Network
CSPOT	Serverless Platform of Things in C
Laminar	Distributed Dataflow Framework
RADICAL	Workflow Toolkit
OpenFOAM	Computational Fluid Dynamics Simulator

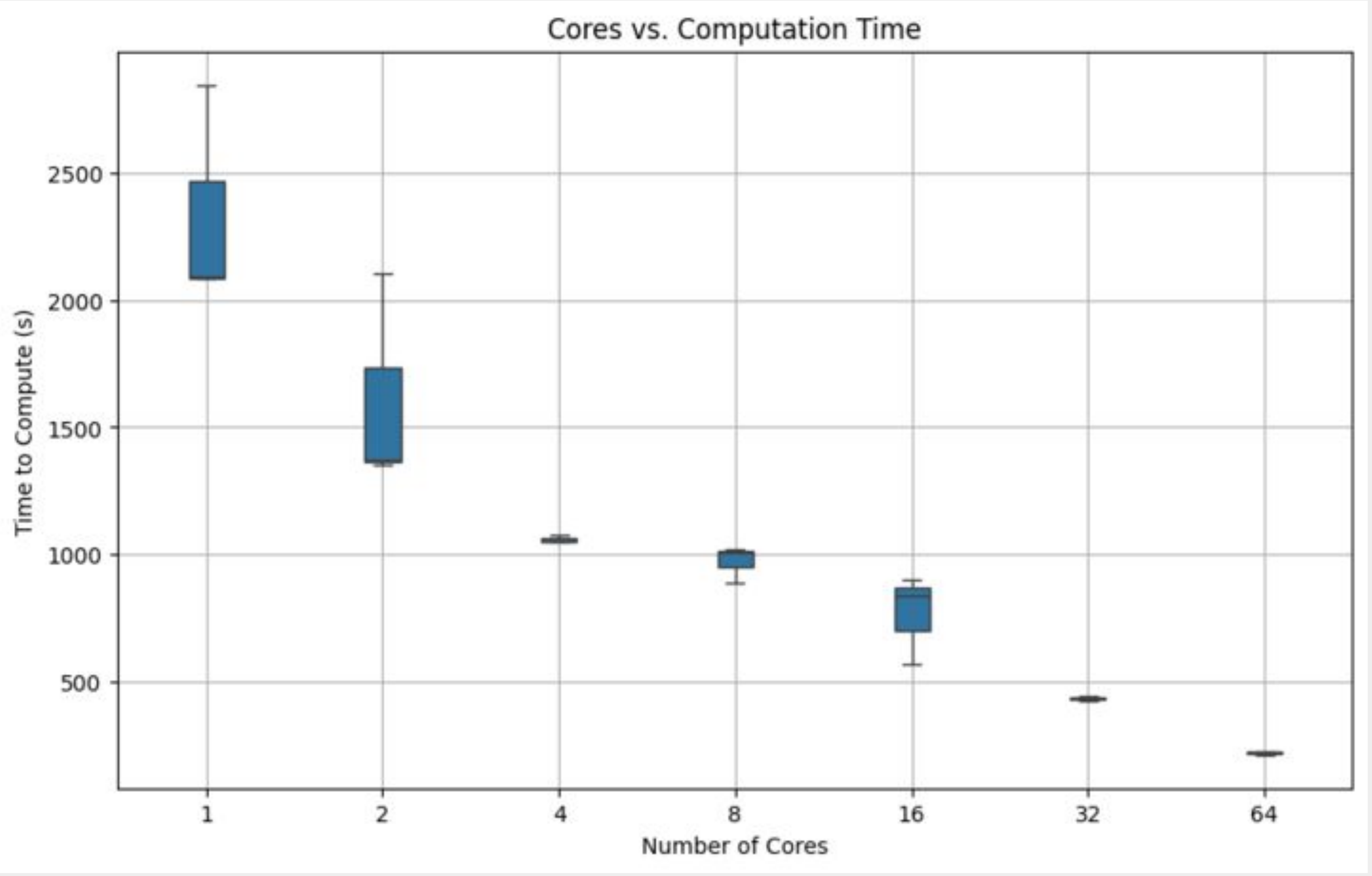


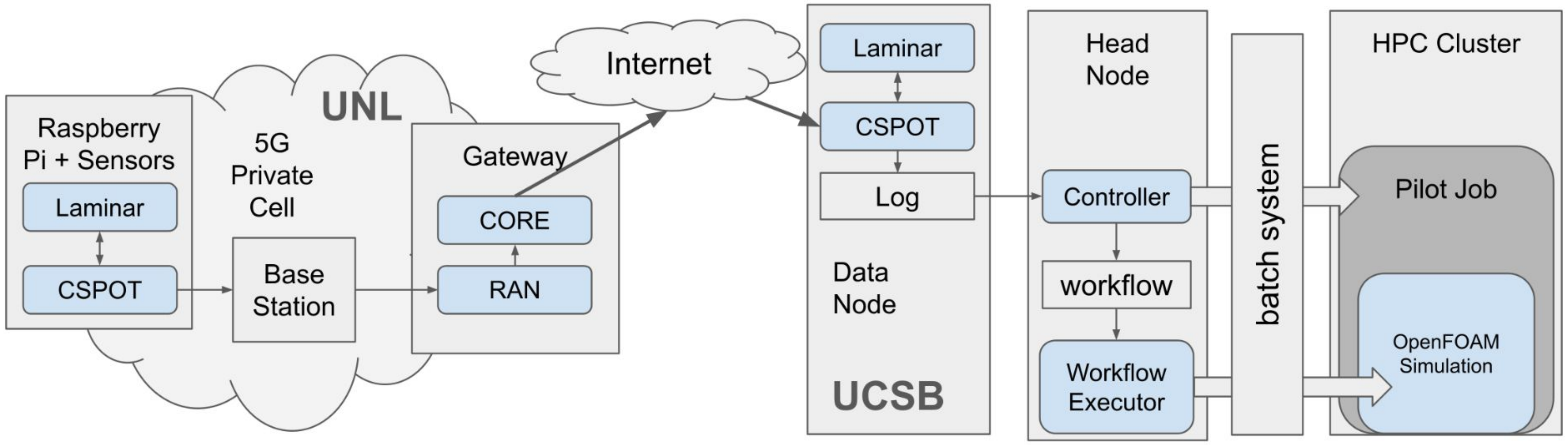
Implementation

The system begins with several sensors planted in the field at UNL collecting weather data. The data is logged to Raspberry Pis via Laminar. Laminar appends data to append-only log files and triggers event-based computations. The Raspberry Pis transmit their data privately over 5G networks to the base station via CSPOT. CSPOT manages secure namespaces for reliable, private data transmissions. The data is then transmitted to UCSB via CSPOT over a 6G RAN and logged with Laminar. Finally, a controller on an HPC head node monitoring the UCSB log file triggers a workflow, which submits an OpenFOAM job to run on the cluster. OpenFOAM simulates the farm using the near real-time data.

Results

Established a working end-to-end prototype that enables near real-time simulation for agriculture. The system's portability has been validated across multiple university's research-class HPC clusters including Notre Dame, Texas Stampede3, and Purdue ANVIL. Comprehensive performance evaluation and scalability testing are currently underway, with detailed results forthcoming. This work establishes a unified digital-physical fabric that tightly integrates advanced wireless networks, sensor data, and leadership-class HPC resources to improve crop management and resource efficiency with applications extending beyond agriculture.





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