nsdi'23

# LinkLab 2.0

## A Multi-tenant Programmable IoT Testbed for Experimentation with Edge-Cloud Integration

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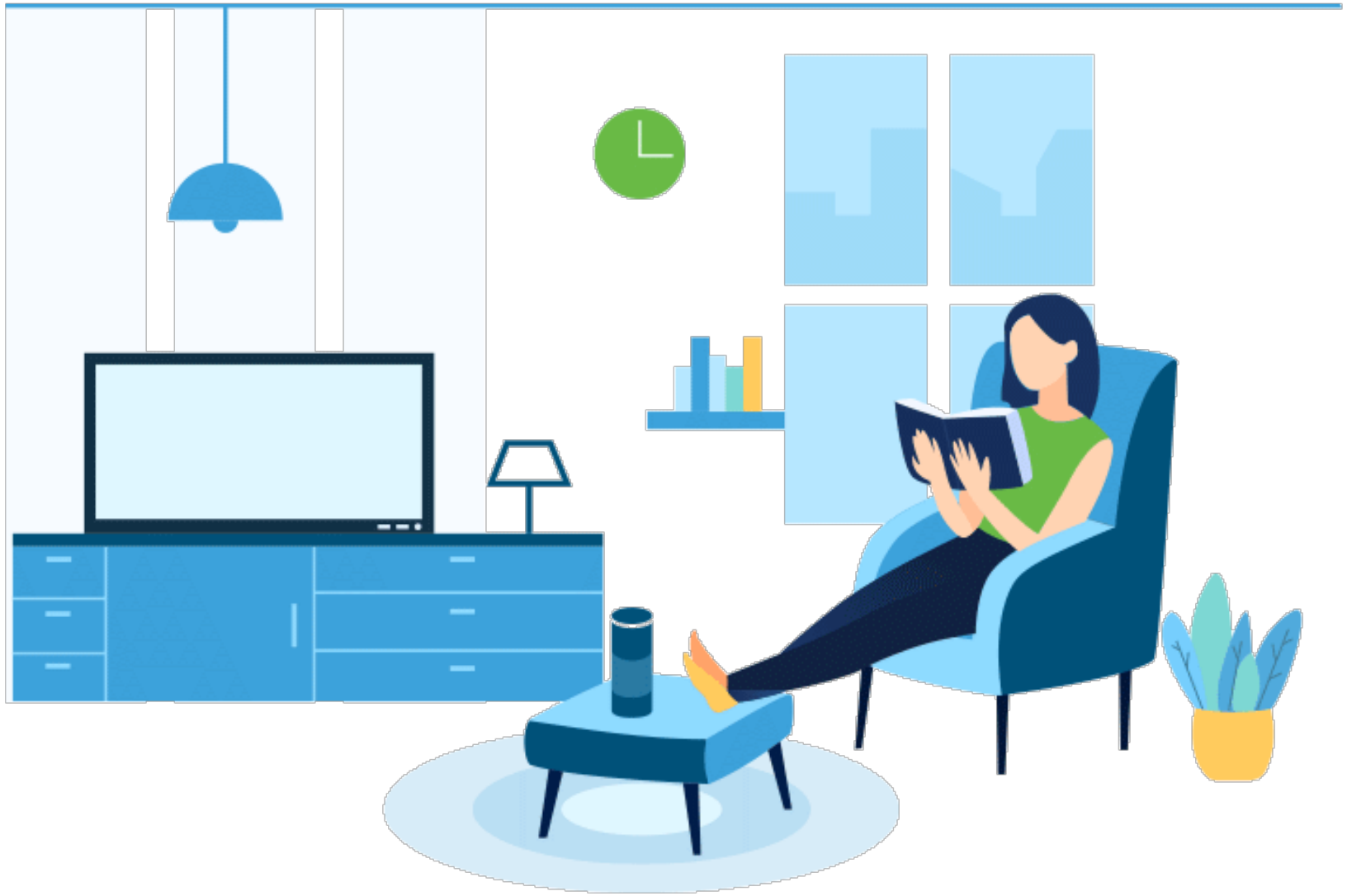
`https://linklab.emnets.cn/`

A · Z · F · T

# Current IoT Applications



Picture source: https://www.hometosmarthome.com/smart-home-support/

# Current IoT Applications


Picture source: https://www.hometosmarthome.com/smart-home-support/

# How to Build a Current IoT Application?

*So many devices/cloud services to choose from and provision…*

# How to Build a Current IoT Application?

*Why not use an **IoT Testbed**?*

# Existing IoT/Wireless Testbeds

# Existing IoT/Wireless Testbeds

| Testbeds | Targeted Scenario | Edge Support | Cloud Support | Online Compilation | Sensing Capability | Instruction Set Architectures |
|---|---|---|---|---|---|---|
| MoteLab | WSN | | | | | |
| Indriya2 | WSN | | | | | |
| FIT IoT Lab | WSN | | | | | |
| EDI Testbed | WSN | | | | | |
| Tutornet | Low-power Wireless | | | | | |
| Smart Santander | City-scale IoT | | | | | |
| COSMOS | Advanced Wireless | | | | | |

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| Indriya2 | WSN | ✗ | ✗ | ✗ | | |
| FIT IoT Lab | WSN | ✗ | ✓* | ✗ | | |
| EDI Testbed | WSN | ✗ | ✗ | ✗ | | |
| Tutornet | Low-power Wireless | ✗ | ✗ | ✗ | | |
| Smart Santander | City-scale IoT | ✗ | ✗ | ✗ | | |
| COSMOS | Advanced Wireless | ✓ | ✓ | ✗ | | |

* works with FIT Cloud Lab to provide cloud support

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| Indriya2 | WSN | ✗ | ✗ | ✗ | + | ARM32, MSP |
| FIT IoT Lab | WSN | ✗ | ✓* | ✗ | + | AVR, Xtensa, ARM32, ARM64 |
| EDI Testbed | WSN | ✗ | ✗ | ✗ | + | MSP, AVR, ARM32 |
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| Smart Santander | City-scale IoT | ✗ | ✗ | ✗ | ++ | AVR, x86 |
| COSMOS | Advanced Wireless | ✓ | ✓ | ✗ | - | (Not mentioned) |

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# IoT Testbed with Cloud-Edge Integration

| Testbeds | Targeted Scenario | Edge Support | Cloud Support | Online Compilation | Sensing Capability | Instruction Set Architectures |
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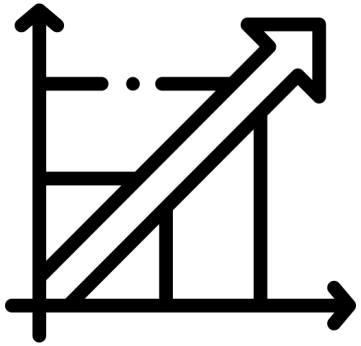
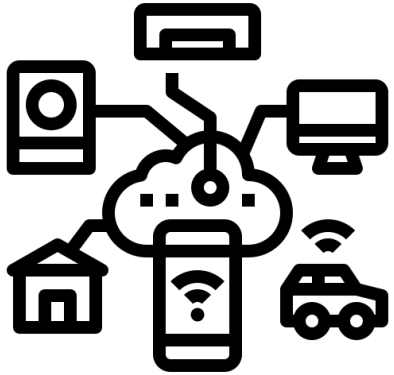
| MoteLab | WSN | ✗ | ✗ | ✗ | + | AVR |
| Indriya2 | WSN | ✗ | ✗ | ✗ | + | ARM32, MSP |
| FIT IoT Lab | WSN | ✗ | ✓* | ✗ | + | AVR, Xtensa, ARM32, ARM64 |
| EDI Testbed | WSN | ✗ | ✗ | ✗ | + | MSP, AVR, ARM32 |
| Tutornet | Low-power Wireless | ✗ | ✗ | ✗ | + | MSP, AVR, ARM32 |
| Smart Santander | City-scale IoT | ✗ | ✗ | ✗ | ++ | AVR, x86 |
| COSMOS | Advanced Wireless | ✓ | ✓ | ✗ | - | (Not mentioned) |
| **LinkLab 2.0** | **Cloud-Edge-IoT Integration** | ✓ | ✓ | ✓ | ++ | MSP, AVR, Xtensa, ARM32, ARM64, x86, GPU |

# Design Goals of LinkLab



*Scalable management*

*Multi-tenancy*



*IoT-Edge-Cloud integration*

*24x7 Reliability*

# Design Goals of LinkLab

Scalable management

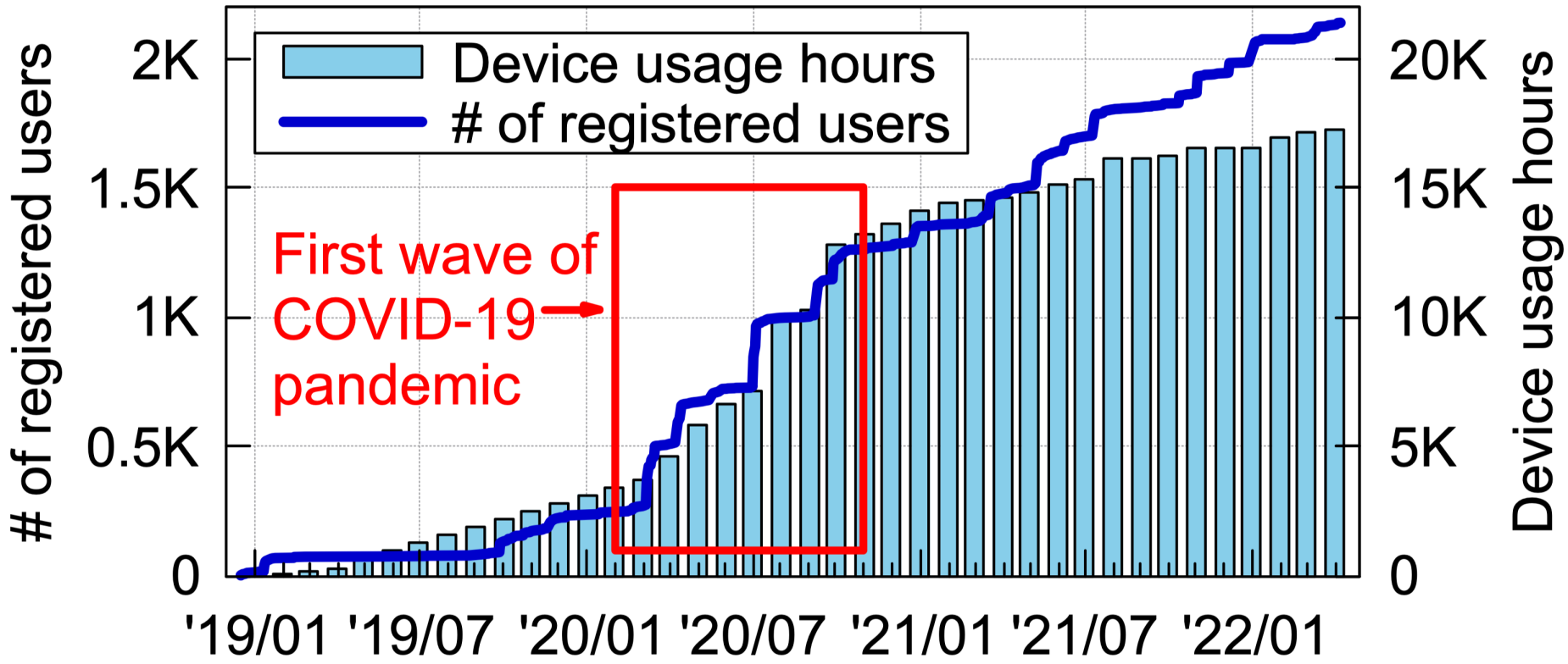
Multi-tenancy

IoT-Edge-Cloud integration

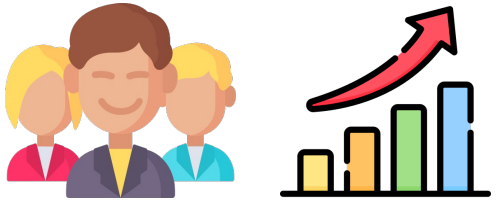
24x7 Reliability

# Why Do We Need Scalability?

- **LinkLab is publicly available during the COVID-19 pandemic**



# Scalability of LinkLab



② *Scalable to bursty user requests*

LinkLab

① *Scalable to heterogeneous devices*

# Scalable to Heterogeneous Devices

*Programmable Devices of LinkLab*

*Cloud*

*Edge*

*IoT*


# Scalable to Heterogeneous Devices

## Management Infrastructure

LinkLab Device Center (LDC)

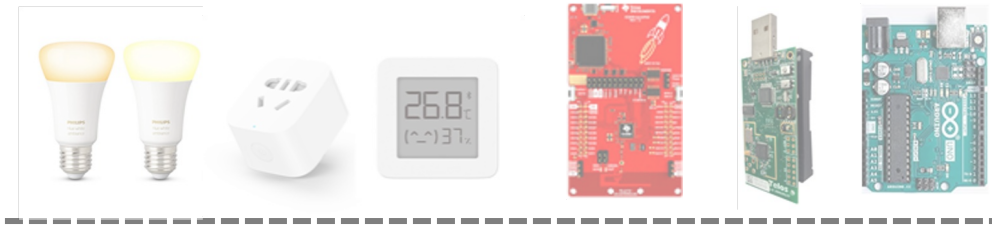
**Challenge 1: Heterogeneous devices?**
- Connectivity
- Computing capability

**Challenge 2: Geographically distributed?**

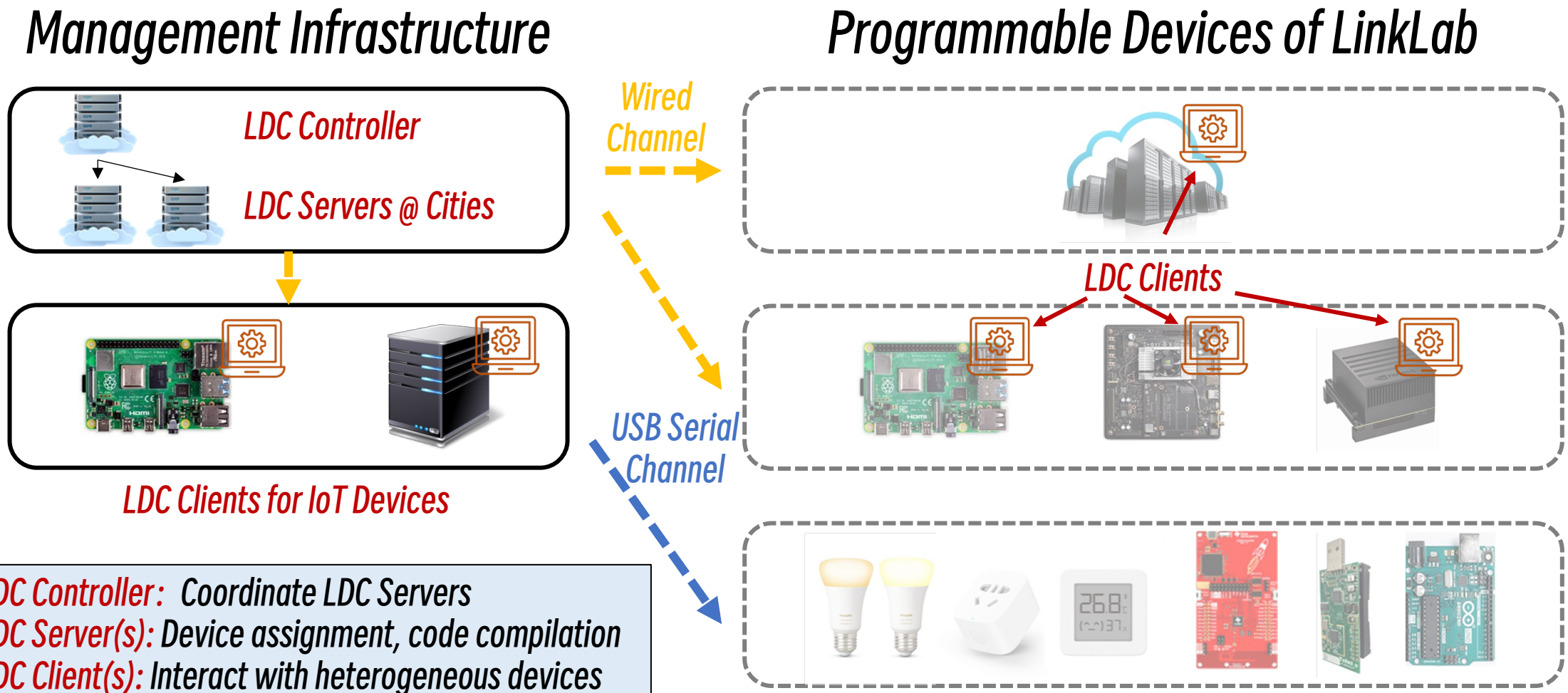
## Programmable Devices of LinkLab

Wired Channel

USB Serial Channel

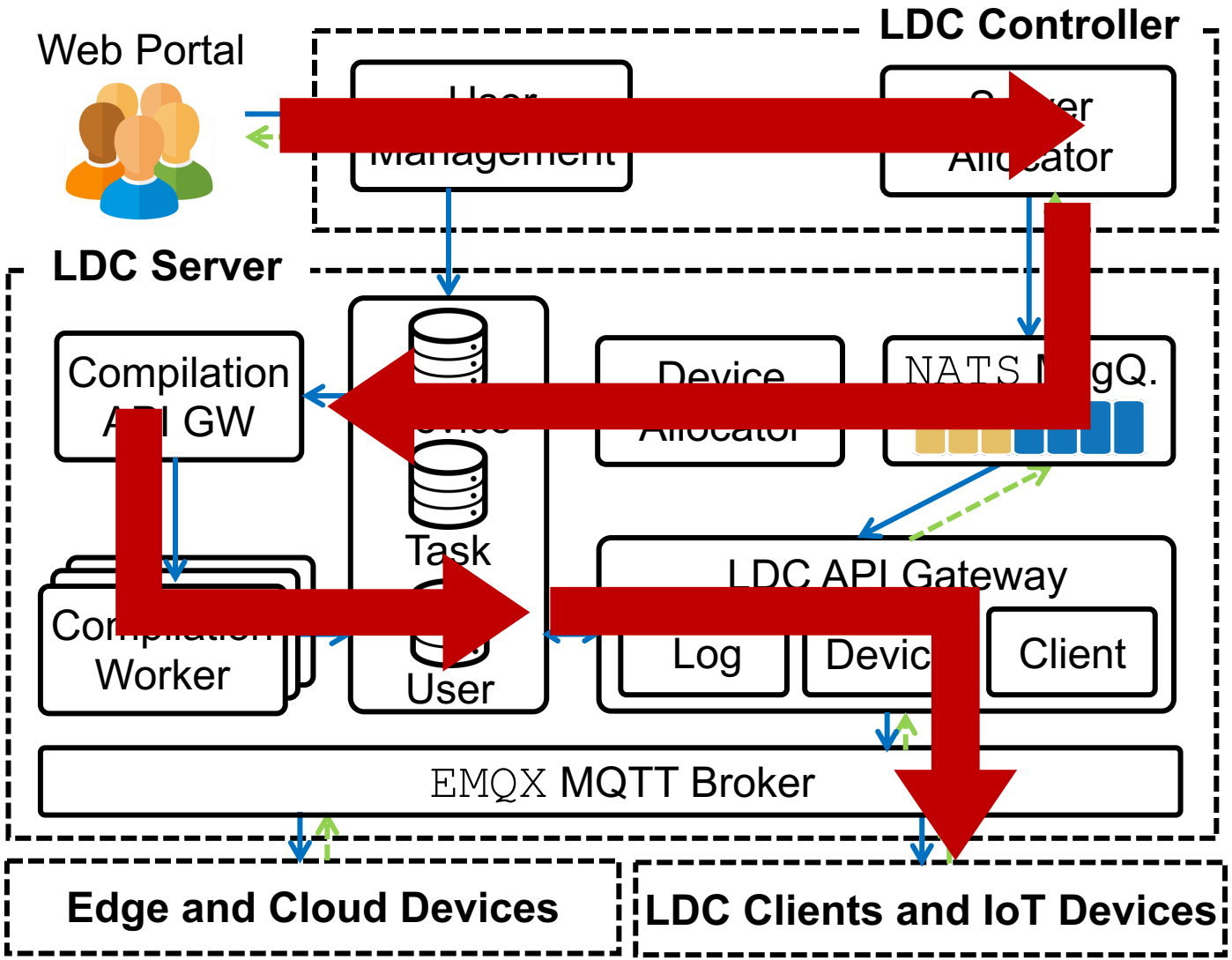


# Tiered Management of LinkLab




- *LDC Controller:* Coordinate LDC Servers
- *LDC Server(s):* Device assignment, code compilation
- *LDC Client(s):* Interact with heterogeneous devices

# Scalable to Bursty User Requests



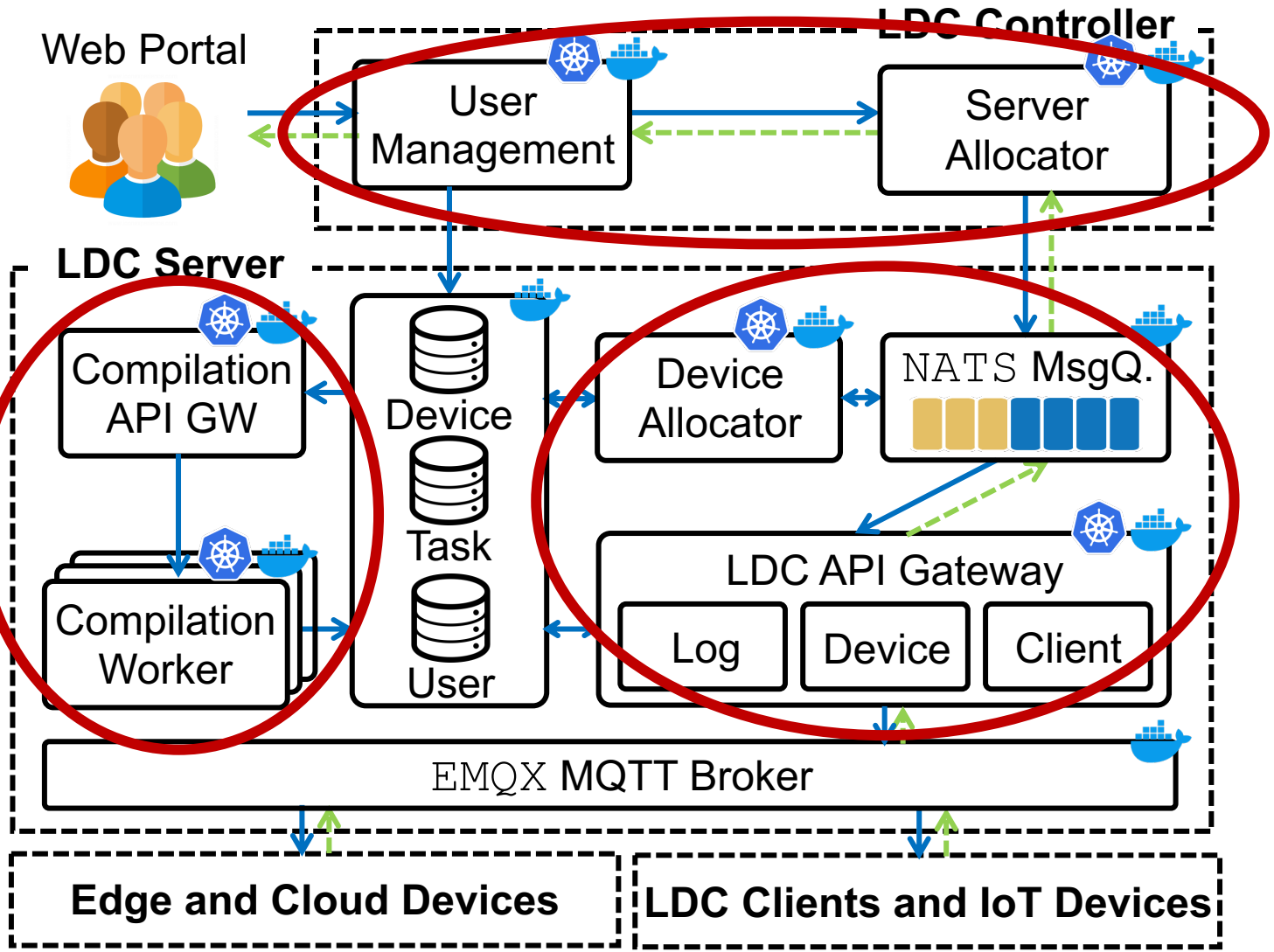

① Server Allocation

② Device Allocation

③ Code Compilation

④ Device Programming

# Scalable to Bursty User Requests

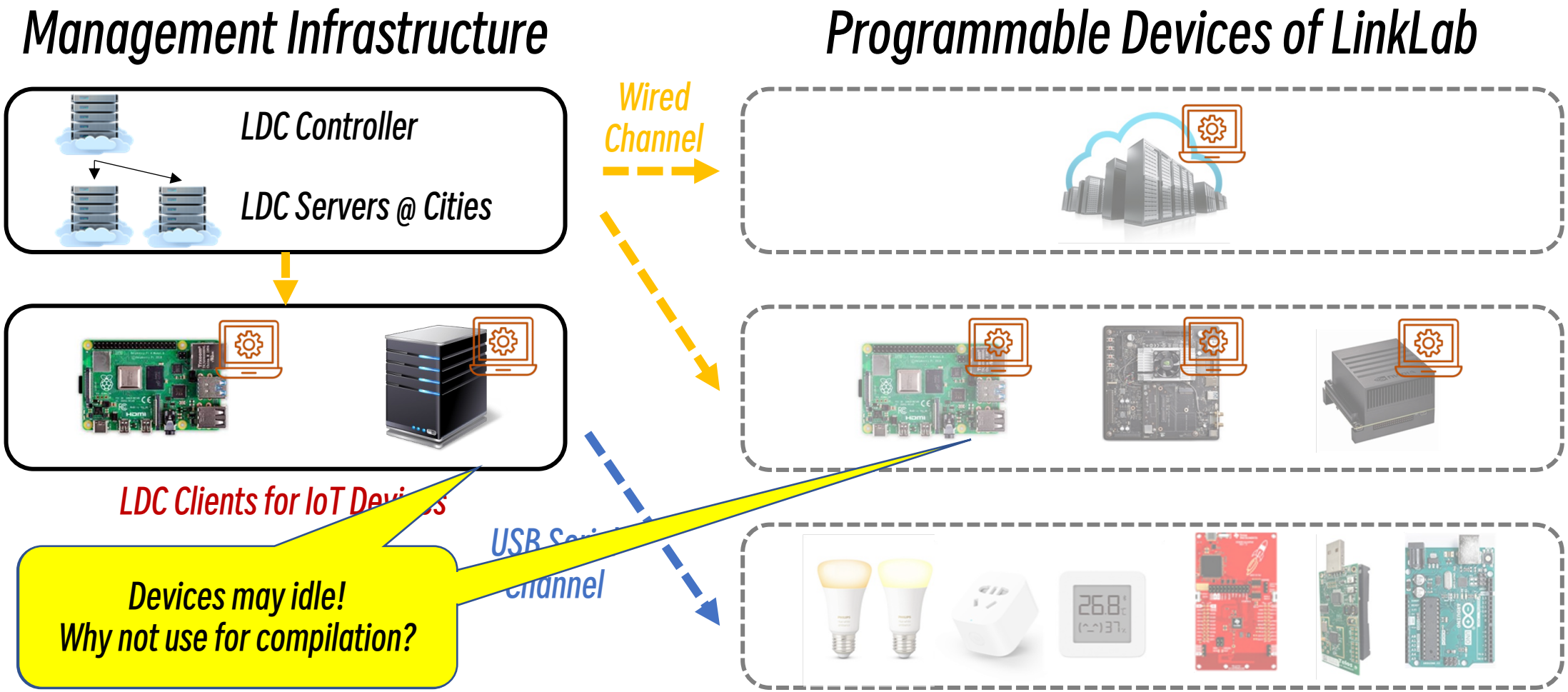



RAM Bottleneck

CPU Bottleneck

CPU Bottleneck

# Dealing with compilation CPU bottlenecks



# Dealing with compilation CPU bottlenecks

*Management Infrastructure*

*LDC Controller*

*LDC Servers @ Cities*

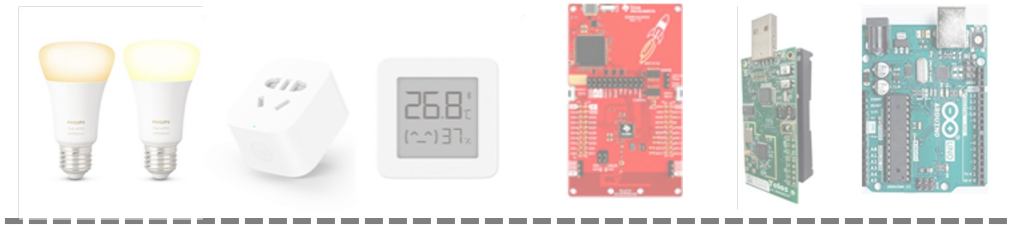
*Programmable Devices of LinkLab*

*Make full use of all (free) devices!*






- *Heterogeneous container scaling*
  - *Dynamic image building*
- *Isolation between scaled services and user tasks*
  - *Linux cgroup*



# Design Goals of LinkLab



Scalable management

Multi-tenancy

IoT-Edge-Cloud integration

24x7 Reliability

# Why Do We Need Multi-tenancy?

- **Require timely execution during**
  - Class time, examination, …
- **Potential tenants**
  - Other cooperative universities of sub-sites
  - Special user groups of main site and sub-sites


# Specifying Tenants with Structured Config.

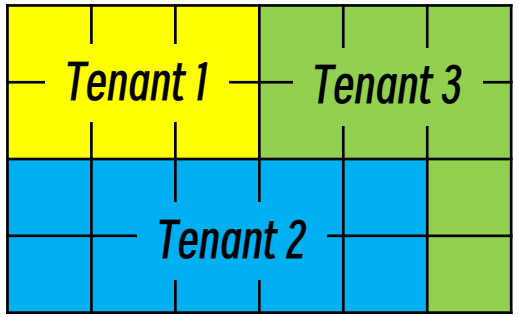
- **Hardware types in multi-tenancy mode**
  - Exclusive
  - Shared
- **Allowed services and service quota being used by tenant**
  - Available services
  - Service concurrency

```
1  TENANT:
2    name: G1@NSDI23
3    user: "University A"
4    hardware_exclusive: "AMega"*80
5    services: "$all"
6    service_quota:      # concurrency
7      compiling: 100    # req/s
8      burning: 100      # req/s
9
```

```
1  TENANT:
2    name: G2@NSDI23
3    user: "University B"
4    hardware_exclusive: "AMega"*20
5    services: "$all"
6    service_quota:      # concurrency
7      compiling: 100    # req/s
8      burning: 100      # req/s
9
```

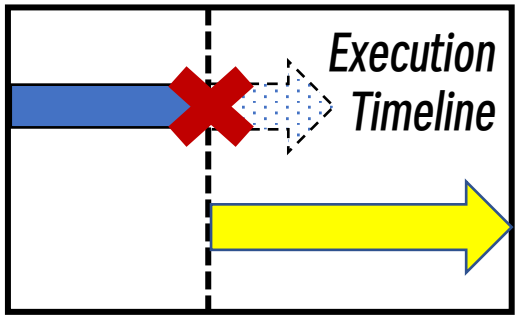
# Device-involved Multi-tenancy

- **For management services**
  - Containerized deployment
  - Resource usage audit and restriction
- **For programmable devices**




*Fixed partition?*

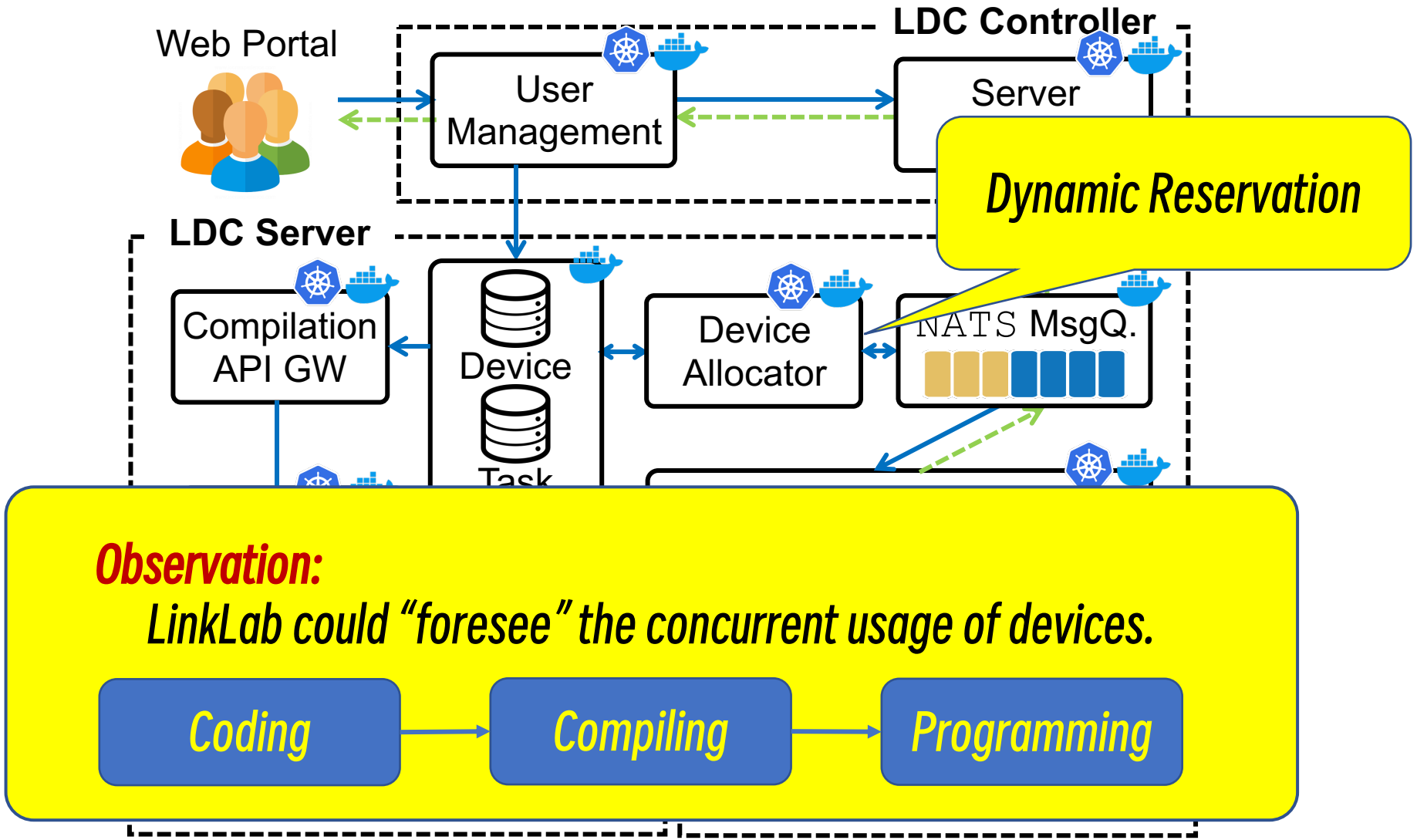
*Low device usage*




*Hard preemption?*

*Bad user experience*

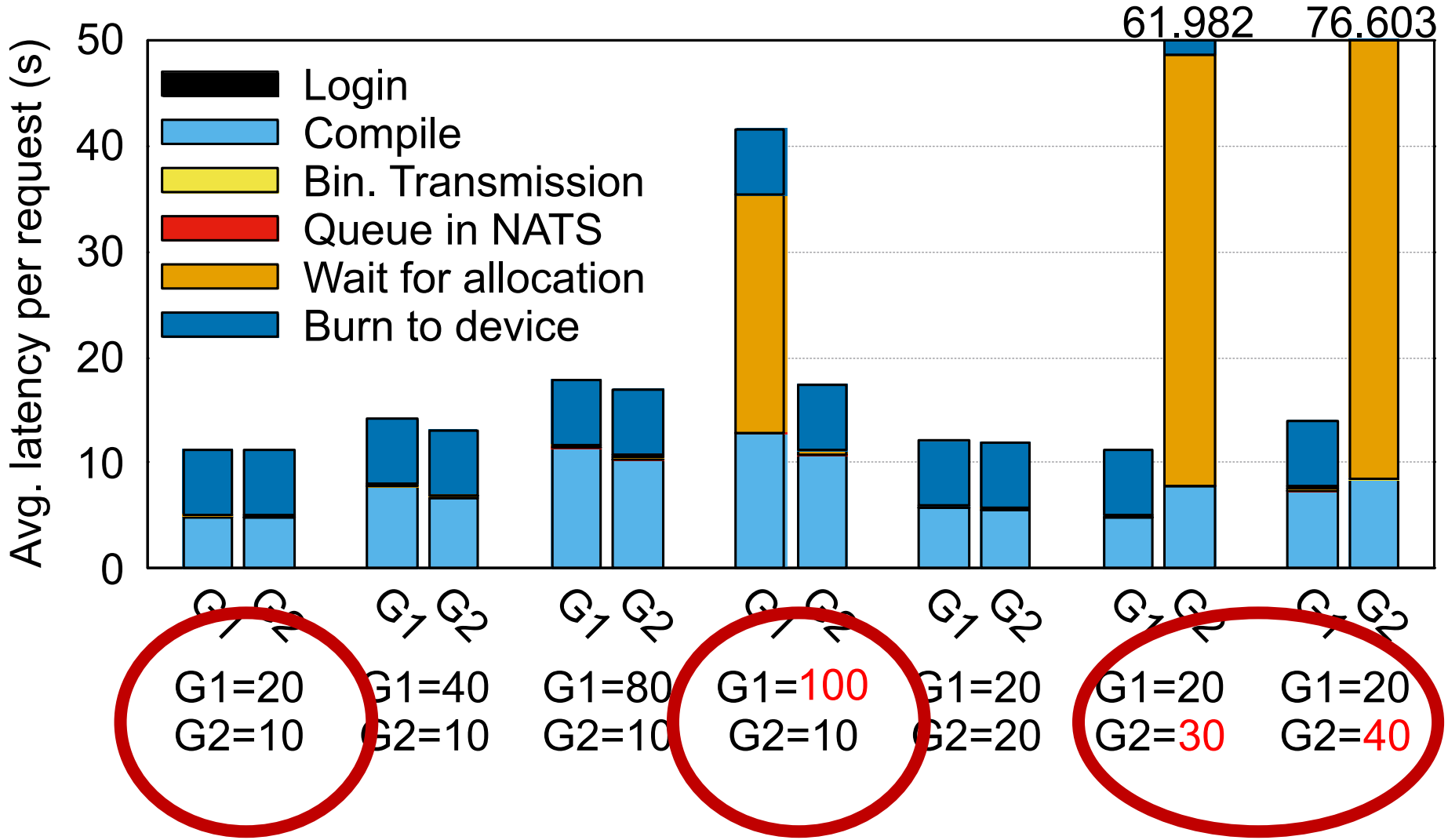
# Device-involved Multi-tenancy



# Evaluation on Multi-tenancy

*Setup*

- *Tenant G1*
  - *80 devices*
- *Tenant G2*
  - *20 devices*



# Other Design Points



Scalable management

Multi-tenancy

§ 3.2
Integrated programming

§ 3.2
Timely edge control based on vNICs

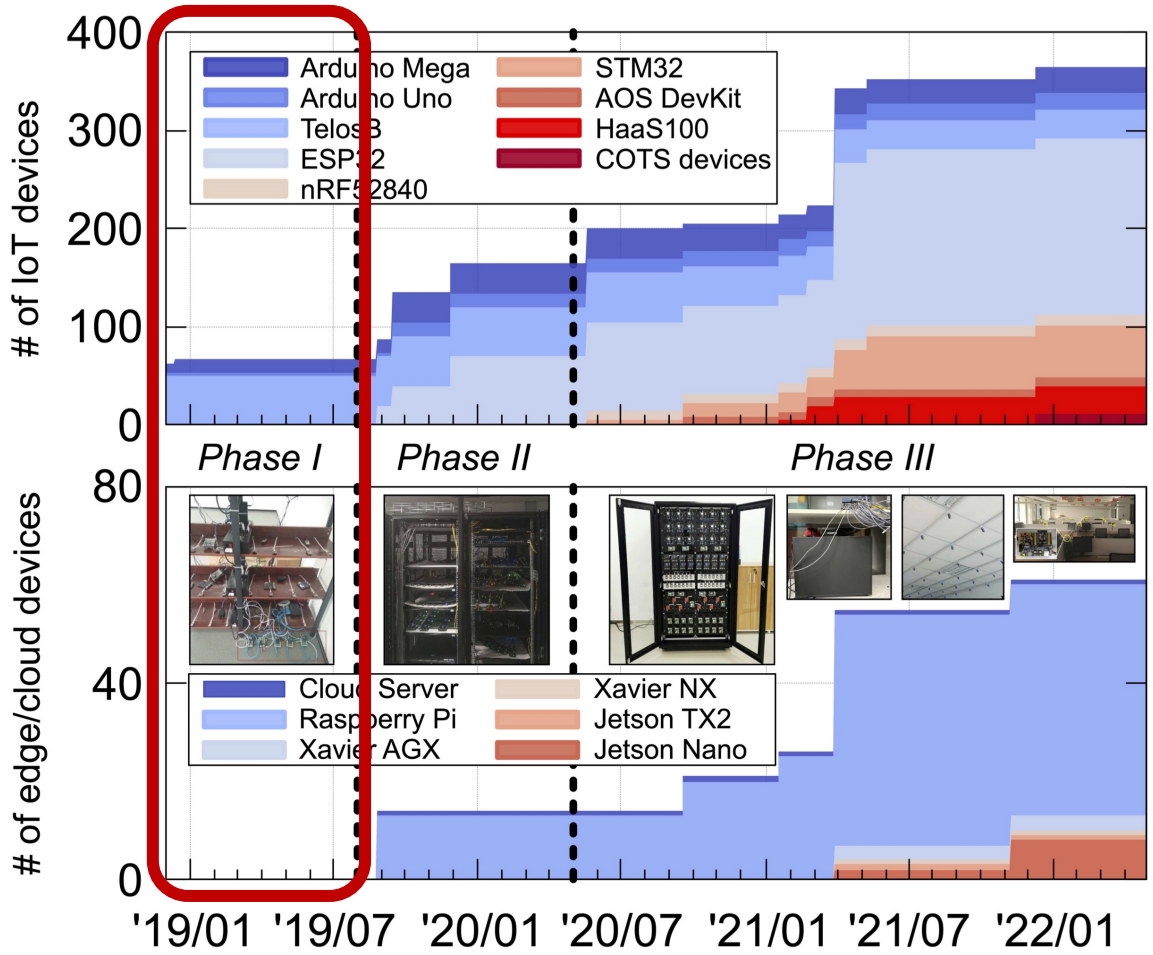
IoT-Edge-Cloud integration

24x7 Reliability

§ 3.4
Proactive and reactive device anomaly detection

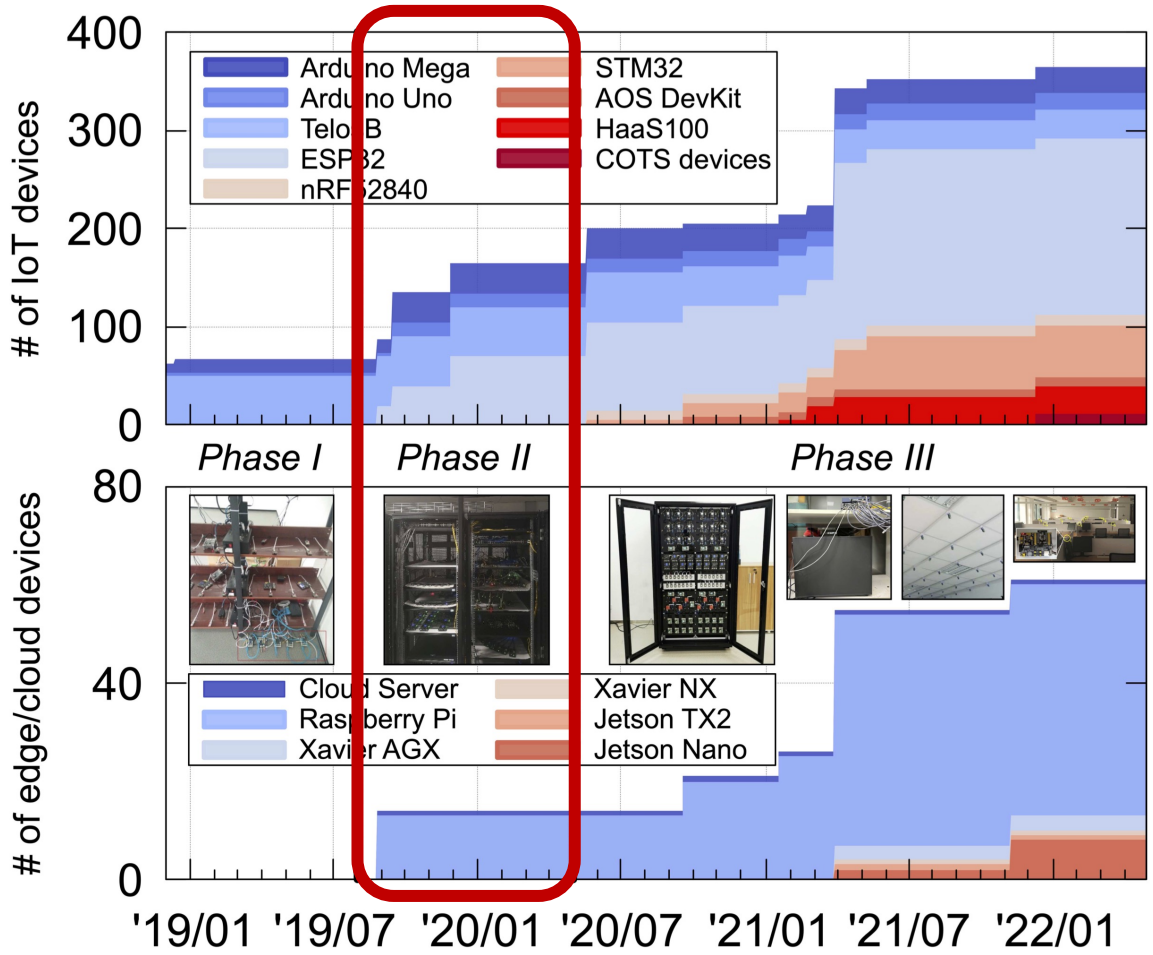
§ 3.4
Service anomaly detection via multi-model log fusion

# Deployment Timeline: Phase I



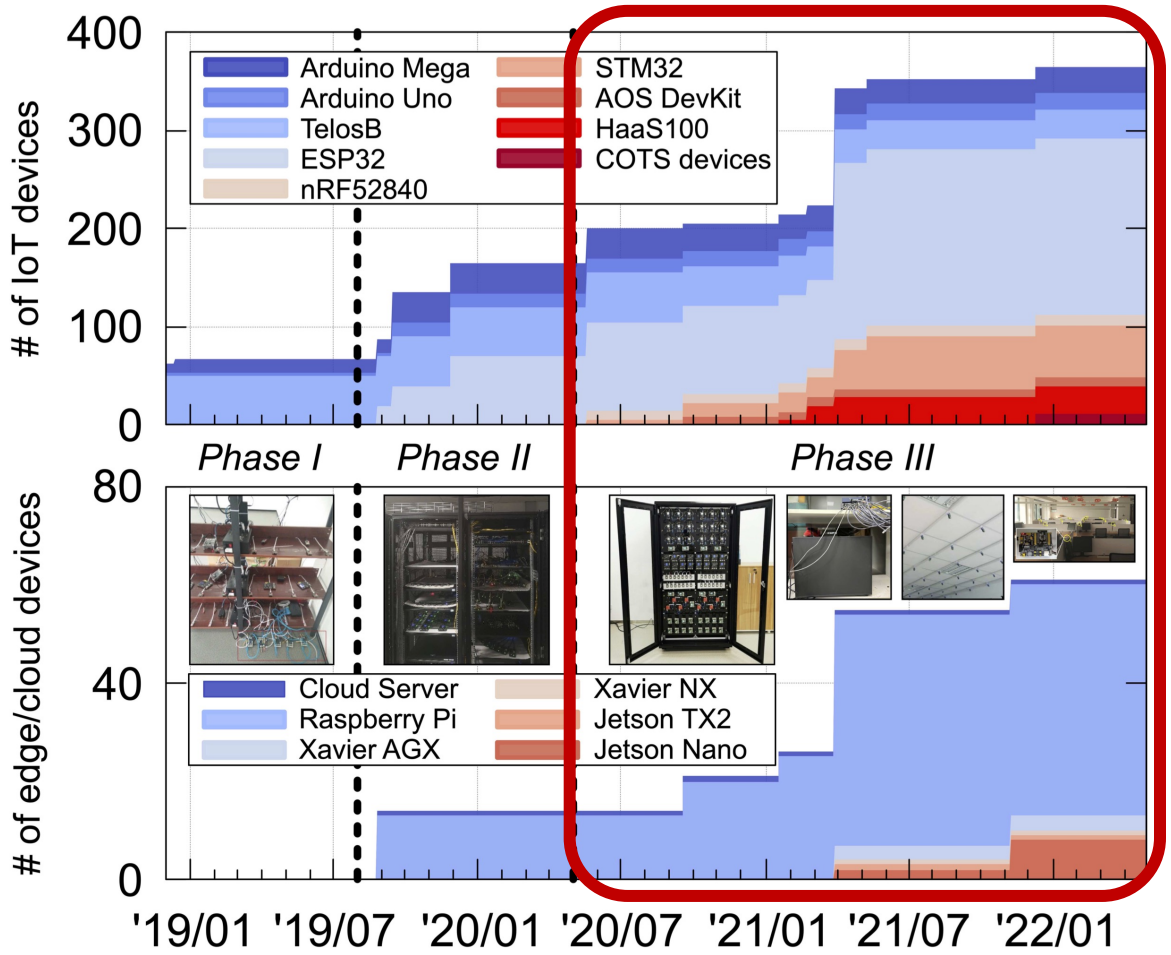

- **2018.12~2019.8**
- **IoT device testbed**
  - ~60 devices
- **Key functionality**
  - Heterogeneous IoT support
  - Device management
  - Online compilation
  - Web-based IDE

# Deployment Timeline: Phase II




- **2019.8~2020.5**
- **Integration with cloud/edge**
  - ~180 devices
- **Key functionality**
  - Cloud/Edge support
    - Cloud server
    - Raspberry Pi
  - New IoT devices
    - ESP32

# Deployment Timeline: Phase III




- **2020.5~Now**
- **Cloud-native, Multi-tenancy**
  - 500+ devices
- **Key functionality**
  - Dynamic service scaling
  - Device-involved multi-tenancy
  - Specific deployment scenarios
    - Office-area BLE mesh
    - Lab-scale MoteLab

# LinkLab Hardware (~2023.03)

IoT devices

**500+ devices**

Cloud server


Edge devices

# LinkLab Hardware (~2023.03)

## IoT devices

- **Scale:** 450 devices
- **ISAs:** MSP, AVR, Xtensa, ARM32, etc.
- **Feature:** COTS devices supported

Cloud server

Edge devices

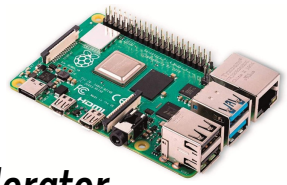
# LinkLab Hardware (~2023.03)

IoT devices

Cloud server

Edge devices

- **Scale:** 80 devices
- **ISAs:** ARM64, etc.
- **Feature:** With AI accelerator




# LinkLab Hardware (~2023.03)

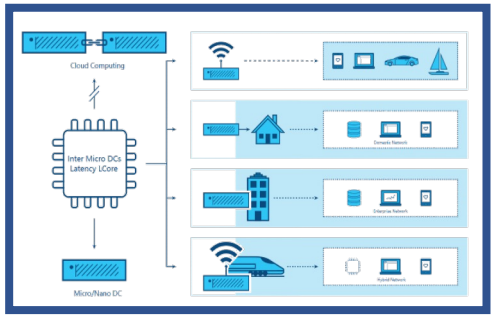
IoT devices

- **Scale:** 36-core CPU devices
- **ISAs:** x86, etc.
- **Feature:** CPU+GPU support

Cloud server

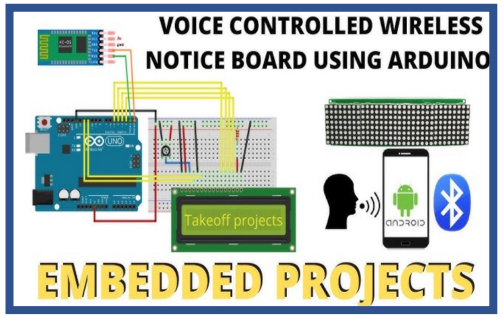
Edge devices

# Potential Research Domains

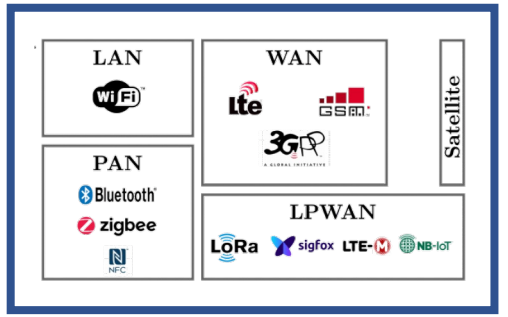



*Cloud-Edge-IoT integrated application*

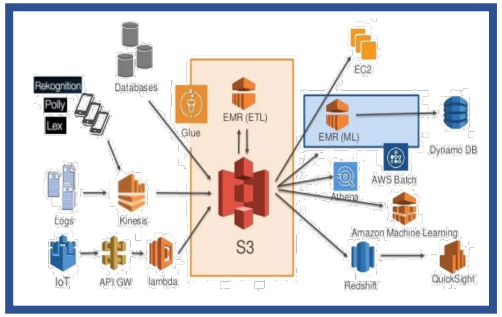
*Industrial Internet of Things*



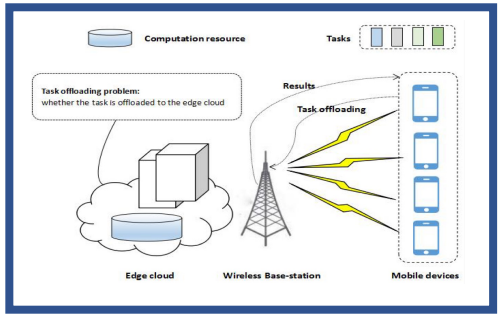

*Wireless and embedded experiments*




*IoT networking protocols*




*FaaS and Serverless computing*




*Offloading algorithms*


*Edge AI*


*Container-based service composition*

# Outreaches of LinkLab

**Educational Institutions**

IoT Curriculum

~40 users/yr.

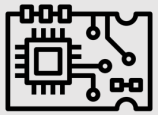
Field work course

~90 users/yr.


Joint IoT lab

~400 users

**Commercial Cooperations**



Online Playground

~150 users

Engineer Certification

~500 users

**Third-party Individuals**

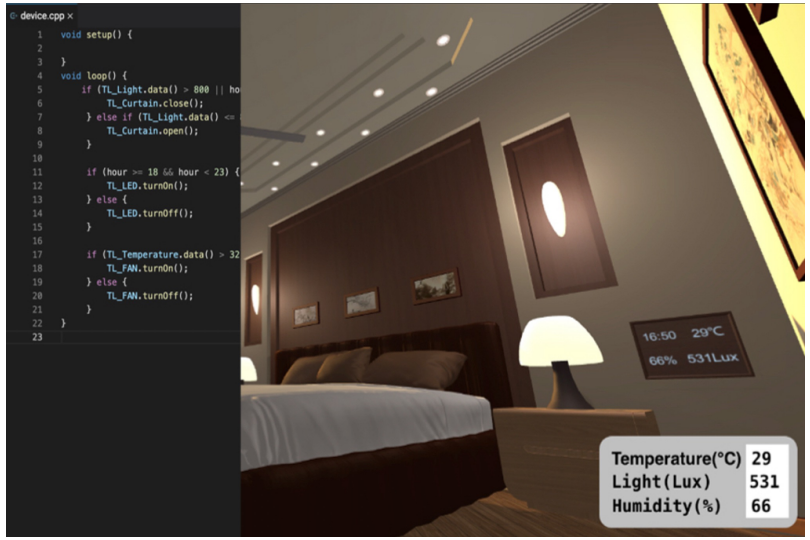

Geek Developers

Self-learners

~1000 users

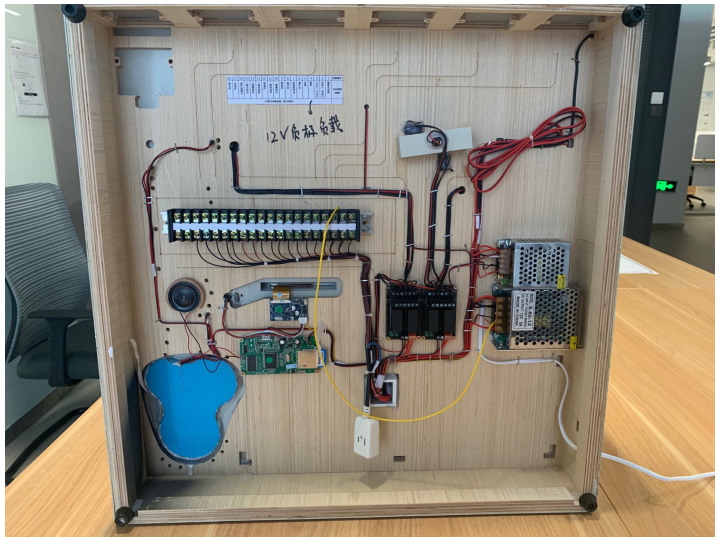
# Outreaches of LinkLab

- **Online-offline integrated smart elderly care education toolkit**




*Online programming lesson with 3D visualized scenario*

*Offline tabletop model (front view)*



*Offline tabletop model (bottom view)*

# LinkLab 2.0

https://linklab.emnets.cn/

An **integrated, multi-tenant** testbed of cloud, edge and IoT:

- 4-year operation, **publicly available**
- **2100+** users, **17,300+** device hours experiment

**Thank you for your attention!**

Wei Dong, Borui Li, Haoyu Li, Hao Wu, Kaijie Gong, Wenzhao Zhang, Yi Gao

If you have any questions, please contact gaoyi@zju.edu.cn