Edge Computing Benefits in Low-Latency IoT Applications

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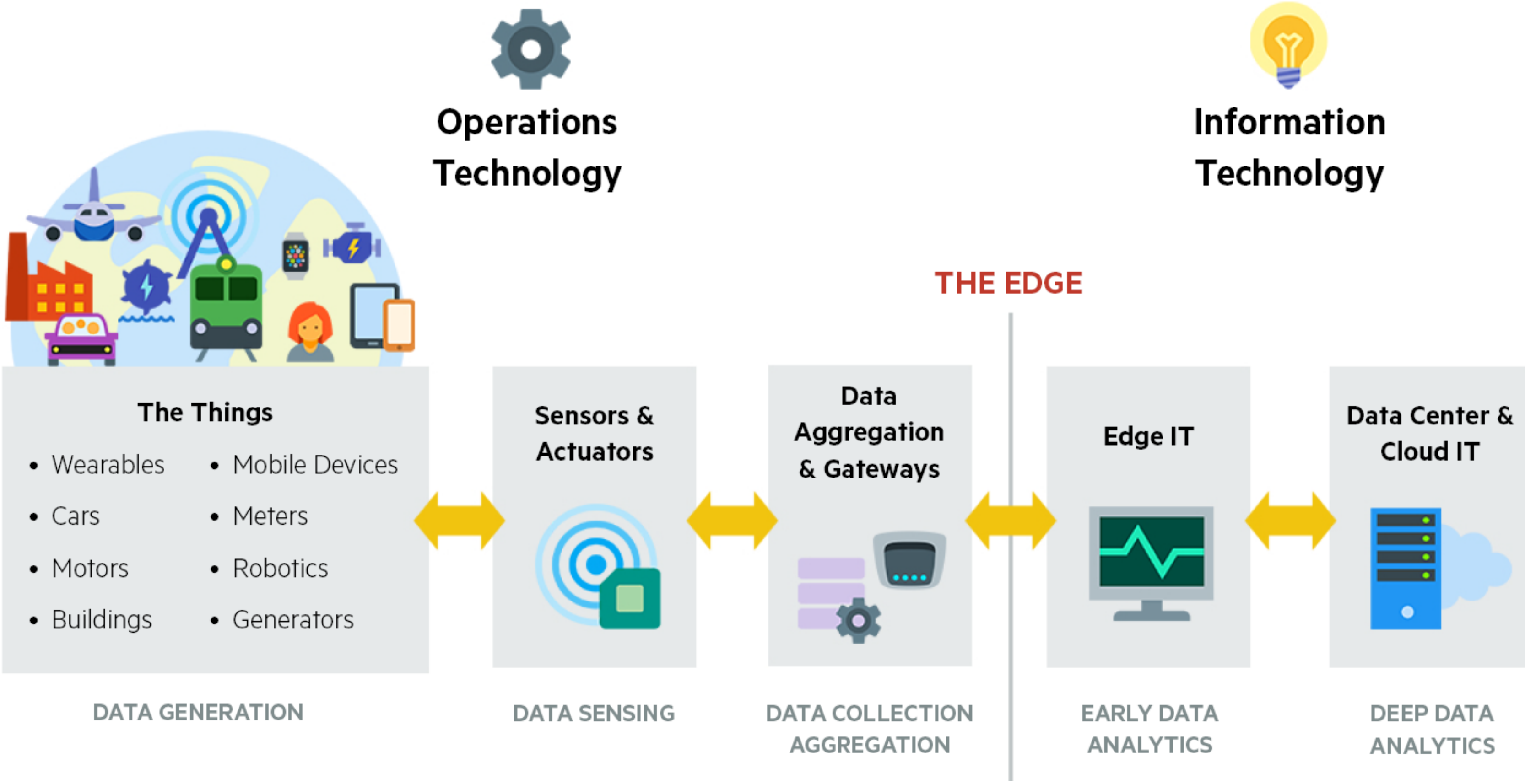
Dipartimento Matematica

Table of contents

Internet of Things



DIPARTIMENTO MATEMATICA

Limitations of traditional Cloud Computing

- **Network Bandwidth**: Sending large volume of data to centralized cloud servers may lead to network congestion.
- **Communication Latency**: The physical distance from the servers introduces substantial processing delays.
- **Resource Inefficiency**: Sending all the collected data to remote servers may be critical for energy-constrained devices.
- **Privacy and Security Concerns**: Continuous data transmissions to external servers may be a potential point of attack.

Emergence of Edge Computing

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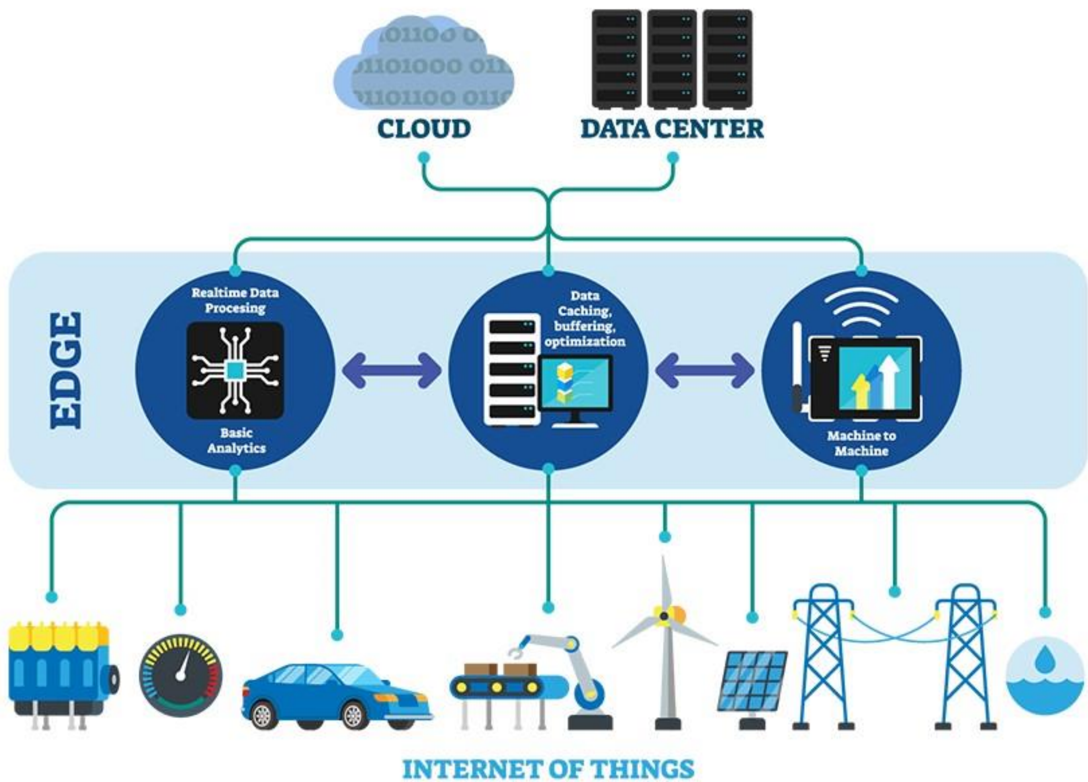
Key features:

- Proximity to data
- Reduced latency
- Real-time processing capabilities
- Enhanced energy efficiency and data security



Edge computing applications

Computing paradigms

- **Centralized Cloud Computing**: Processes all data in remote servers.
- **Fog Computing**: Localized processing on network devices like routers.
- **Cloudlet Computing**: Small servers near IoT devices for low-latency tasks.
- **Mobile Edge Computing (MEC)**: Computing at mobile network edges for real-time responses.
- **Mobile Ad Hoc Cloud (MAC)**: Dynamic use of nearby mobile devices for processing.
- **Hybrid Computing**: Combines cloud and edge for balanced performance.

A study on Mobile Edge Computing (MEC)

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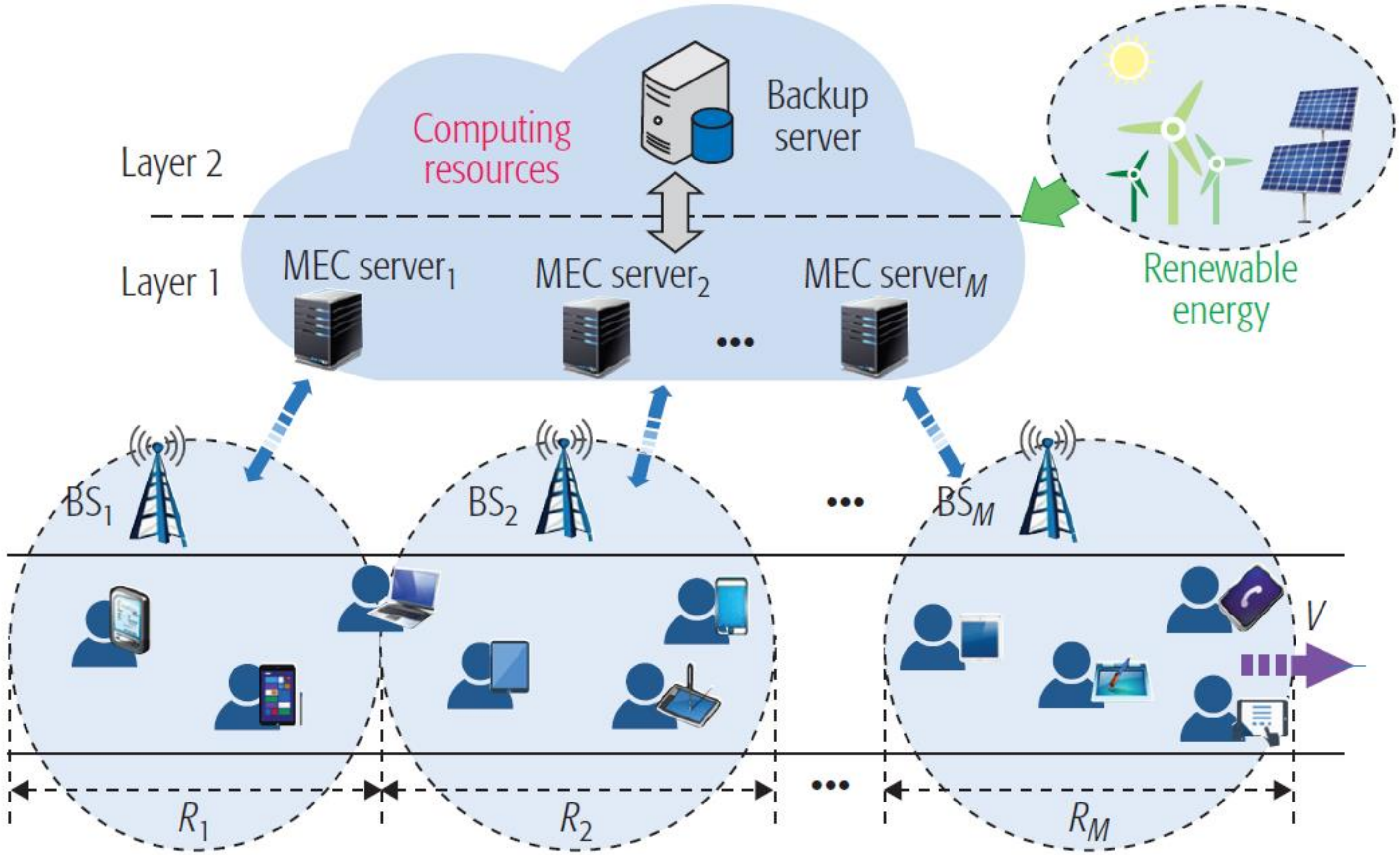

Figure 2. Mobility-aware hierarchical MEC framework.

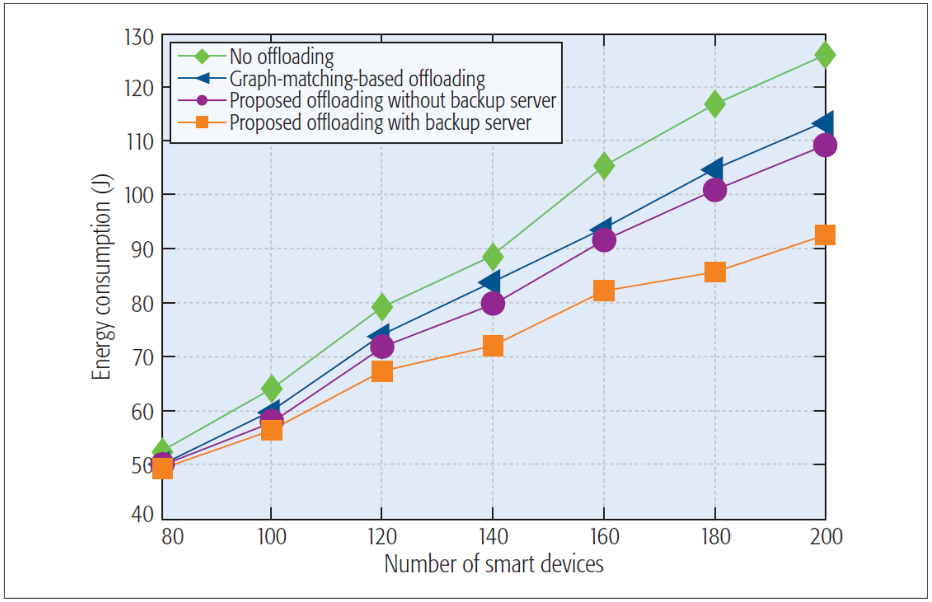

Figure 4. Energy consumption of the task execution with different schemes.

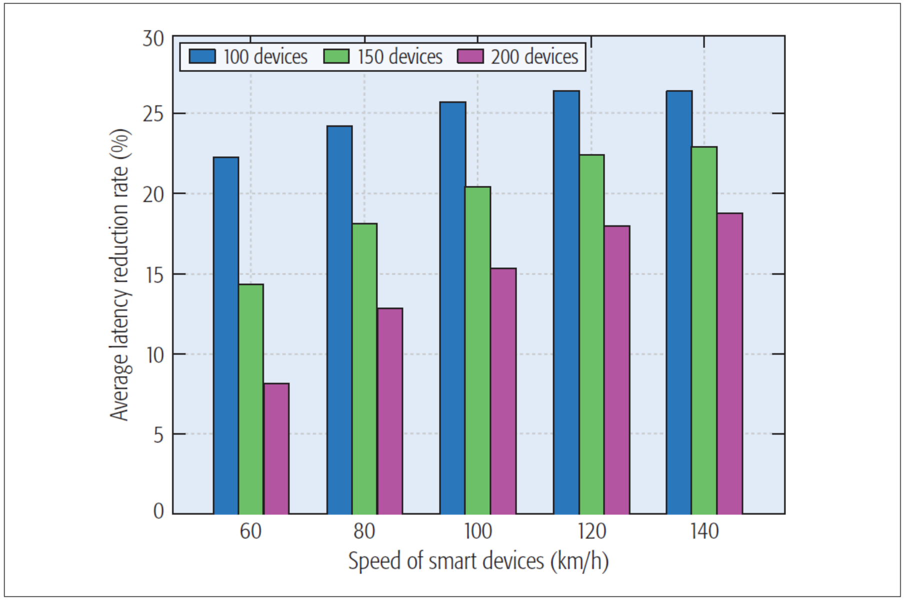

Figure 5. Comparison of average task latency reduction rates with various device speeds.

A study on mobile gaming

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- **Objective**: Evaluate the impact of edge computing on latency in resource-demanding mobile gaming applications.
- **Experimental Setup**:
  - Platform: GamingAnywhere, an open-source cloud gaming framework.
  - Client Device: Google Nexus 5 mobile phone.
  - Server: Workstation with Intel Xeon E3-1230 CPU, 16GB RAM, and NVIDIA GPUs.
  - Network Technologies: Wi-Fi and LTE.
- **Comparison Scenarios**:
  - Local Edge Deployment: Server located at the network edge.
  - Specialized Cloud Infrastructure: Centralized cloud computing.
- **Key Metrics**: Response delay, comprising processing delay (PD), network delay (ND), and playout delay (PD).

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A study on mobile gaming

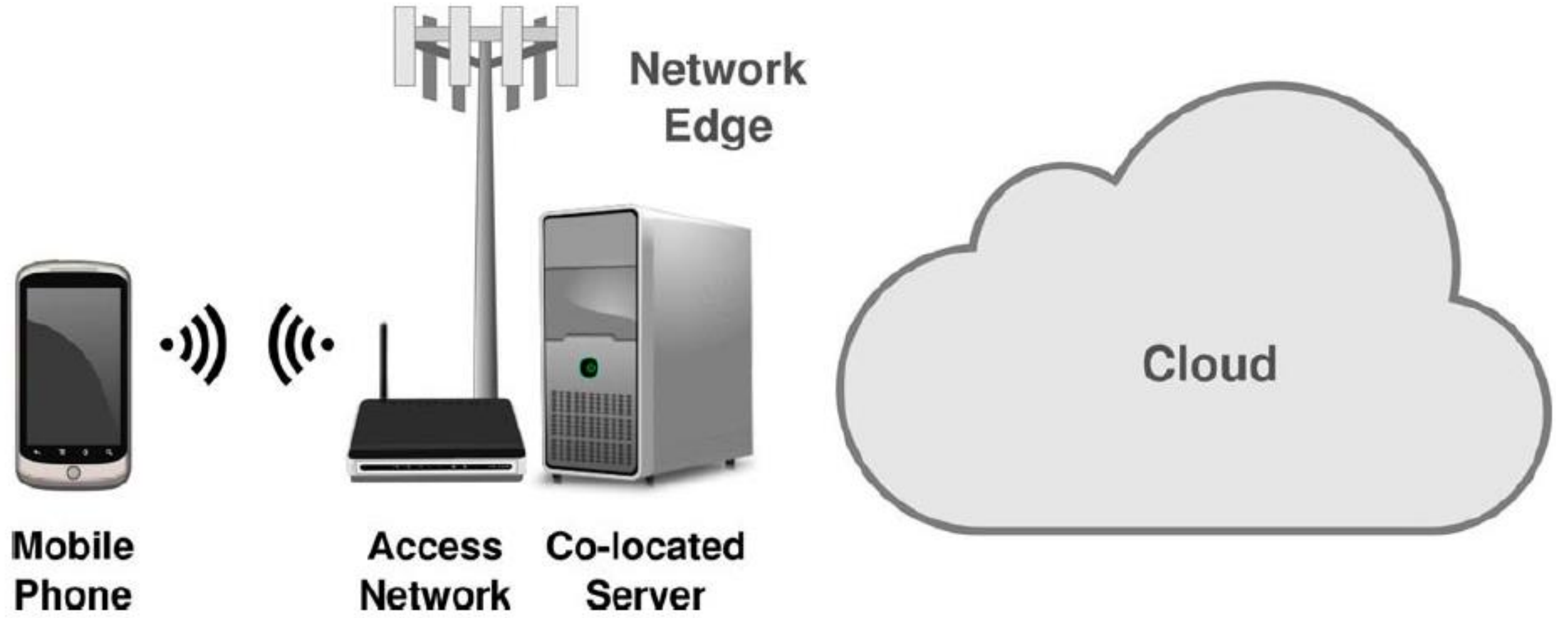

Fig. 2. Testbed setup used for the network edge scenario.

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- **Findings**:
  - **Latency**: Edge setup achieved network delay (ND) of <20ms, outperforming cloud setups which showed >50ms delay.
  - **Virtualization**: Containers delivered near-bare-metal performance, while hypervisor virtualization incurred ~30% higher processing delay.
  - **Resolution**: Full HD processing times at the edge were significantly better compared to centralized cloud setups.
- **Conclusion**: Proximity of computational resources crucial to enhance UX.

A study on industrial manufacturing

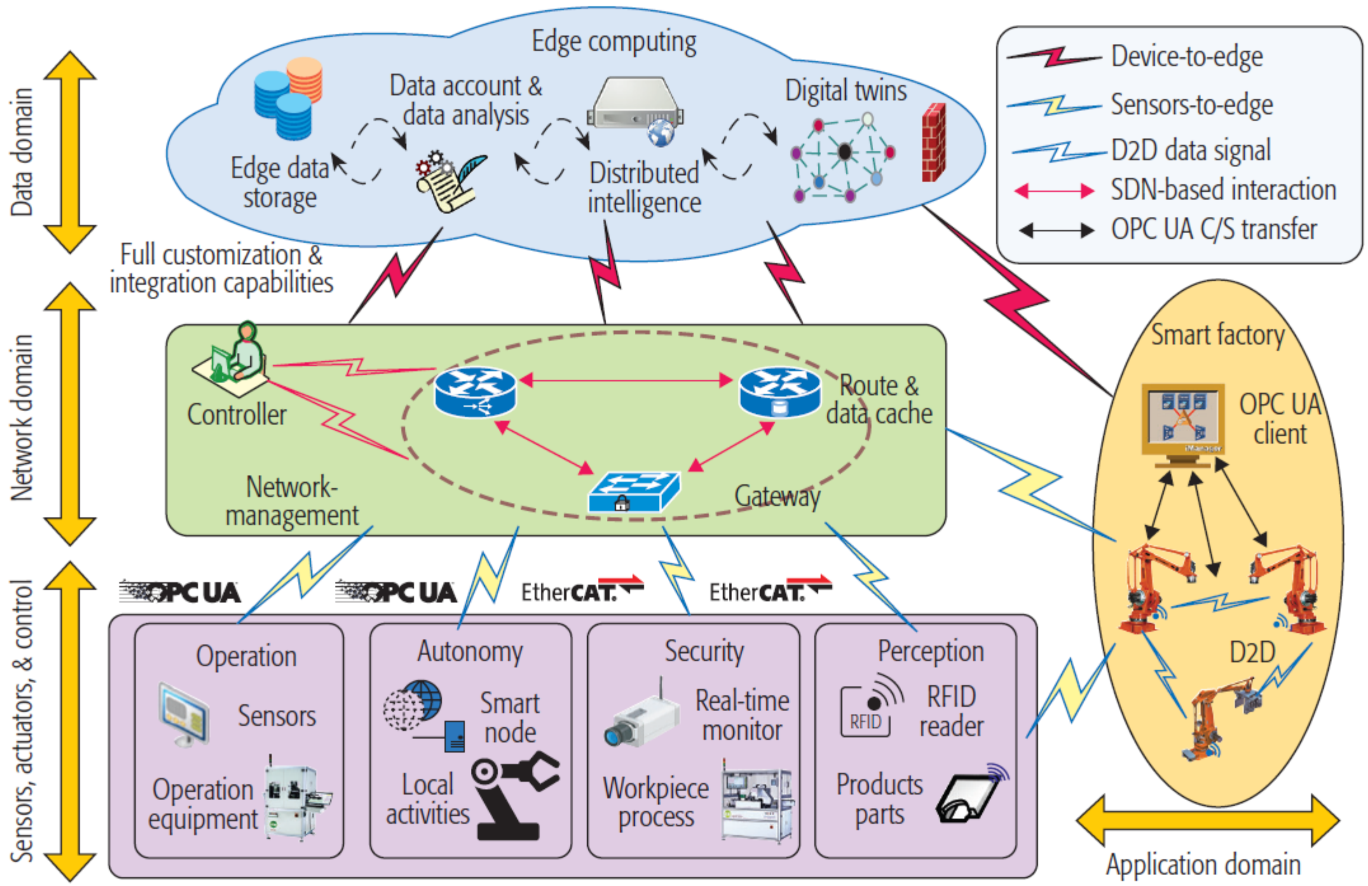

Figure 1. Architecture of an edge computing platform in IoT-based manufacturing.

A study on industrial manufacturing

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- **Objective**: Explores the integration of edge computing in IoT-based manufacturing to address latency, real-time analytics, and resource efficiency.

- **Key Benefits**:
  - **Active Maintenance**:
    - Enhanced responsiveness through localized processing.
    - Case study on candy packaging line showed a 60% reduction in network traffic (from 16-17 Mb/s to 5-6 Mb/s) with improved order handling efficiency.
  - **Cloud-Edge Cooperation:**
    - Cloud layers handle long-term data analysis, maintenance planning, and knowledge mining.
    - Edge layers focus on real-time processing, security, and immediate business logic execution.

A study on industrial manufacturing

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- **Implementation Challenges**:
  - Protocol compatibility across legacy and modern systems.
  - Real-time processing for time-sensitive manufacturing tasks.
  - Integration with existing infrastructure while ensuring scalability.

- **Future Directions**:
  - Evolution of digital twins for manufacturing optimization.
  - Enhanced autonomous systems for process management.
  - Continued development in network optimization for seamless edge-cloud integration.

Open research challenges

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1. **Heterogeneity**: Need for standardized programming models for diverse devices.
2. **Resource Management**: Efficient allocation in dynamic, constrained environments.
3. **Security & Privacy**: Safeguarding sensitive data against evolving threats.
4. **Data Handling**: Efficient preprocessing of large IoT data volumes.
5. **System Reliability**: Ensuring consistent and scalable service delivery.

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References

1. N. Hassan, S. Gillani, E. Ahmed, I. Yaqoob and M. Imran, "The Role of Edge Computing in Internet of Things," in IEEE Communications Magazine, vol. 56, no. 11, pp. 110-115, November 2018, doi: 10.1109/MCOM.2018.1700906.
2. G. Premsankar, M. Di Francesco and T. Taleb, "Edge Computing for the Internet of Things: A Case Study," in IEEE Internet of Things Journal, vol. 5, no. 2, pp. 1275-1284, April 2018, doi: 10.1109/JIOT.2018.2805263.
3. B. Chen, J. Wan, A. Celesti, D. Li, H. Abbas and Q. Zhang, "Edge Computing in IoT-Based Manufacturing," in IEEE Communications Magazine, vol. 56, no. 9, pp. 103-109, Sept. 2018, doi: 10.1109/MCOM.2018.1701231.
4. K. Zhang, S. Leng, Y. He, S. Maharjan and Y. Zhang, "Mobile Edge Computing and Networking for Green and Low-Latency Internet of Things," in IEEE Communications Magazine, vol. 56, no. 5, pp. 39-45, May 2018, doi: 10.1109/MCOM.2018.170