Challenges in Edge Computing I

Chapter 7

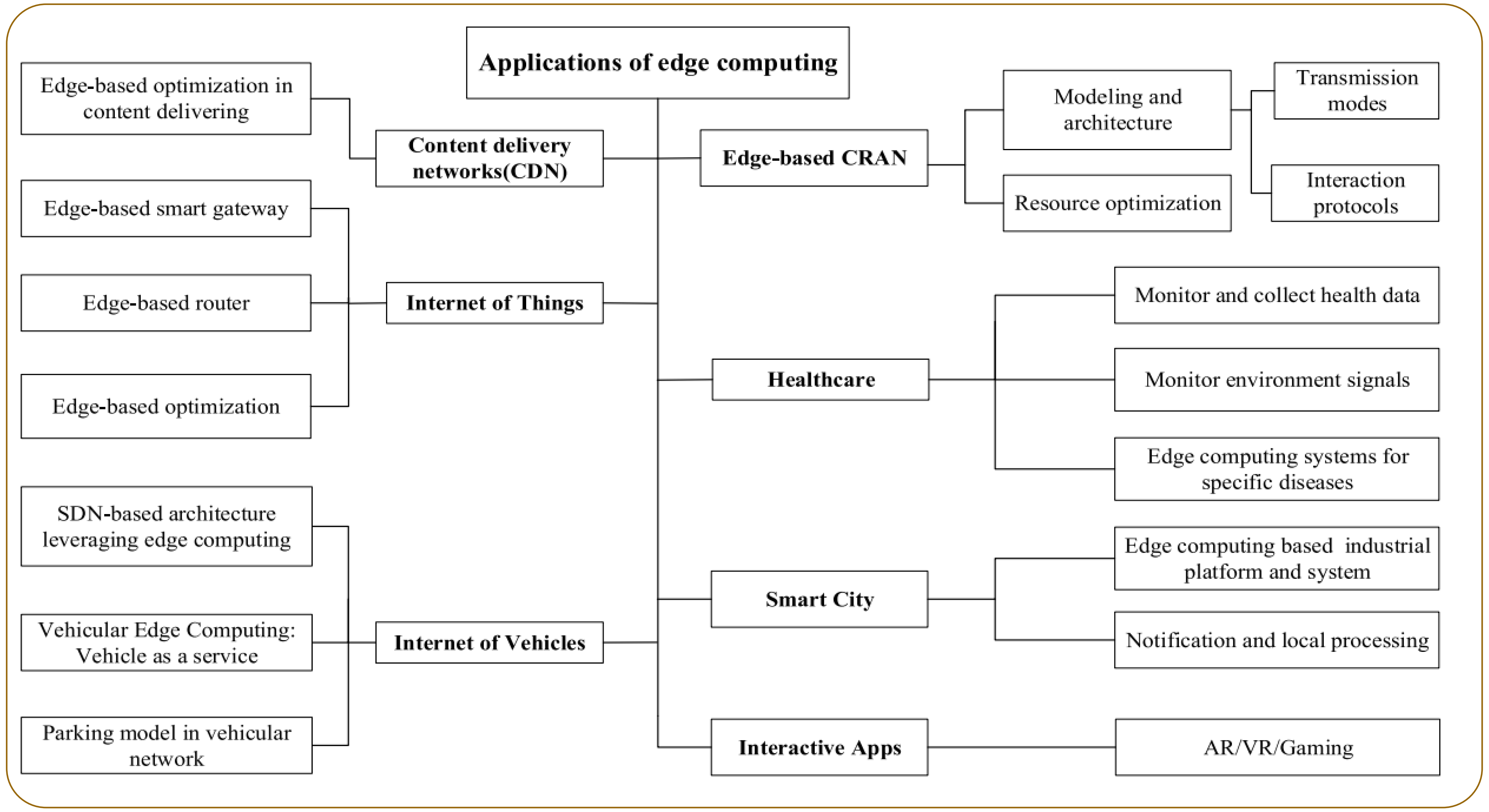
Topic: Manufacturing | Telecom | Healthcare | Smart cities

Outline

- ❑ Manufacturing
  - Predictive maintenance
  - 4-domain architecture
  - LSTM anomaly detection
- ❑ Telecommunications
  - Edge cloud computing
  - URLLC & mm-wave
  - 5G / VR / V2X
- ❑ Healthcare
  - IoMT monitoring
  - Remote patient care
  - Data privacy
- ❑ Smart Cities
  - ADMM & situational awareness
  - YOLO + SORT
  - DRL & DECIoT
- ❑ Summary & Practice

Overview

Where Edge Computing Applies



A taxonomy of edge computing applications

- By processing data at the source, edge computing brings low latency, bandwidth savings, privacy and real-time decisions to industry after industry. This lecture covers four.

Cross-cutting benefits

Lower latency
Real-time decisions near the data

Less bandwidth
Send only what matters upstream

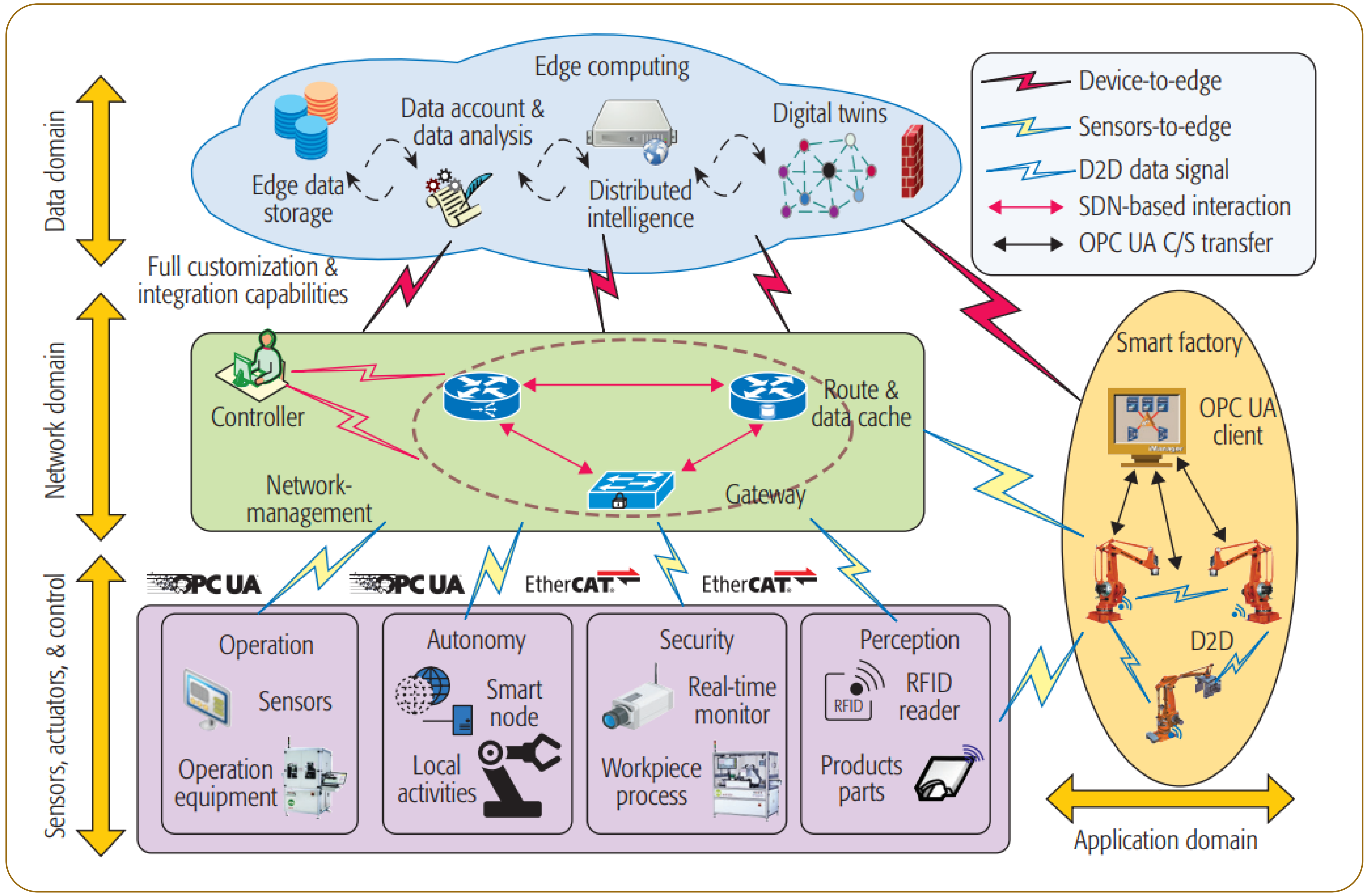
Privacy
Sensitive data stays local

Resilience
Works despite weak connectivity

Yongli Zhao et al. “Edge computing and networking: A survey on infrastructures and applications”. In: IEEE Access 7 (2019), pp. 101213–101230.

Manufacturing

Four domain manufacturing model



Edge computing in IoT-based manufacturing

➢ Four domains

Devices Sensors, robots, RFID — the physical shop floor.

Network SDN + time-sensitive networking (TSN) for real-time data flow.

Data Cleaning, feature extraction, distributed intelligence.

Applications Intelligent process management & digital twins.

Case study: smart-factory active maintenance cut network load 60%.

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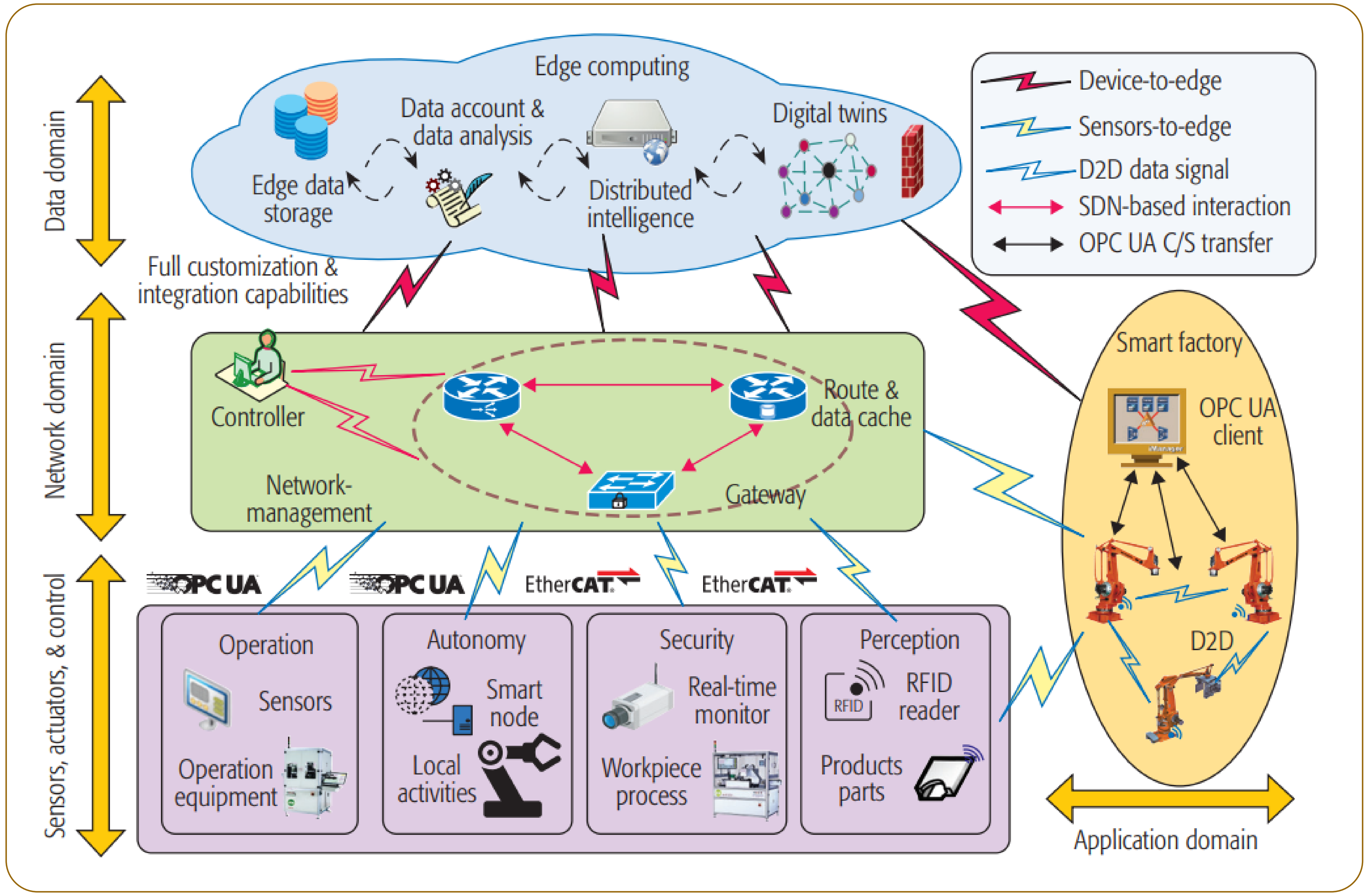
Manufacturing

Four domain manufacturing model



Edge computing in IoT-based manufacturing

➢ Challenges in manufacturing domain

Flexible middleware
Middleware must flex across diverse machines & vendors.

Diverse protocols
Managing many communication protocols on one floor.

Real-time + security
Guaranteeing real-time processing without weakening security.

Limited edge resources
Reliability despite constrained compute & unstable cloud links.

Baotong Chen et al. “Edge computing in IoT-based manufacturing”. In: IEEE Communications Magazine 56. 9 (2018), pp. 103–109.

Manufacturing: Use Cases

Predictive maintenance & anomaly detection

LSTM anomaly detection

Discrete-workshop approach: energy-data preprocessing + an LSTM production-anomaly model catch spindle failure & tool wear — just 3.5% detection error.

Autoencoder fault detection

An edge-cloud-app framework with a distributed stacked sparse autoencoder models nonlinear sensor relations for real-time fault detection.

Cyber-physical production

Edge acts as an intermediary between machines. Local cloud services preprocess AR-device data for real-time human-machine interaction.

Why the edge wins

Rapid autonomous decisions, lower latency & network load, privacy, and resilience despite unstable cloud links.

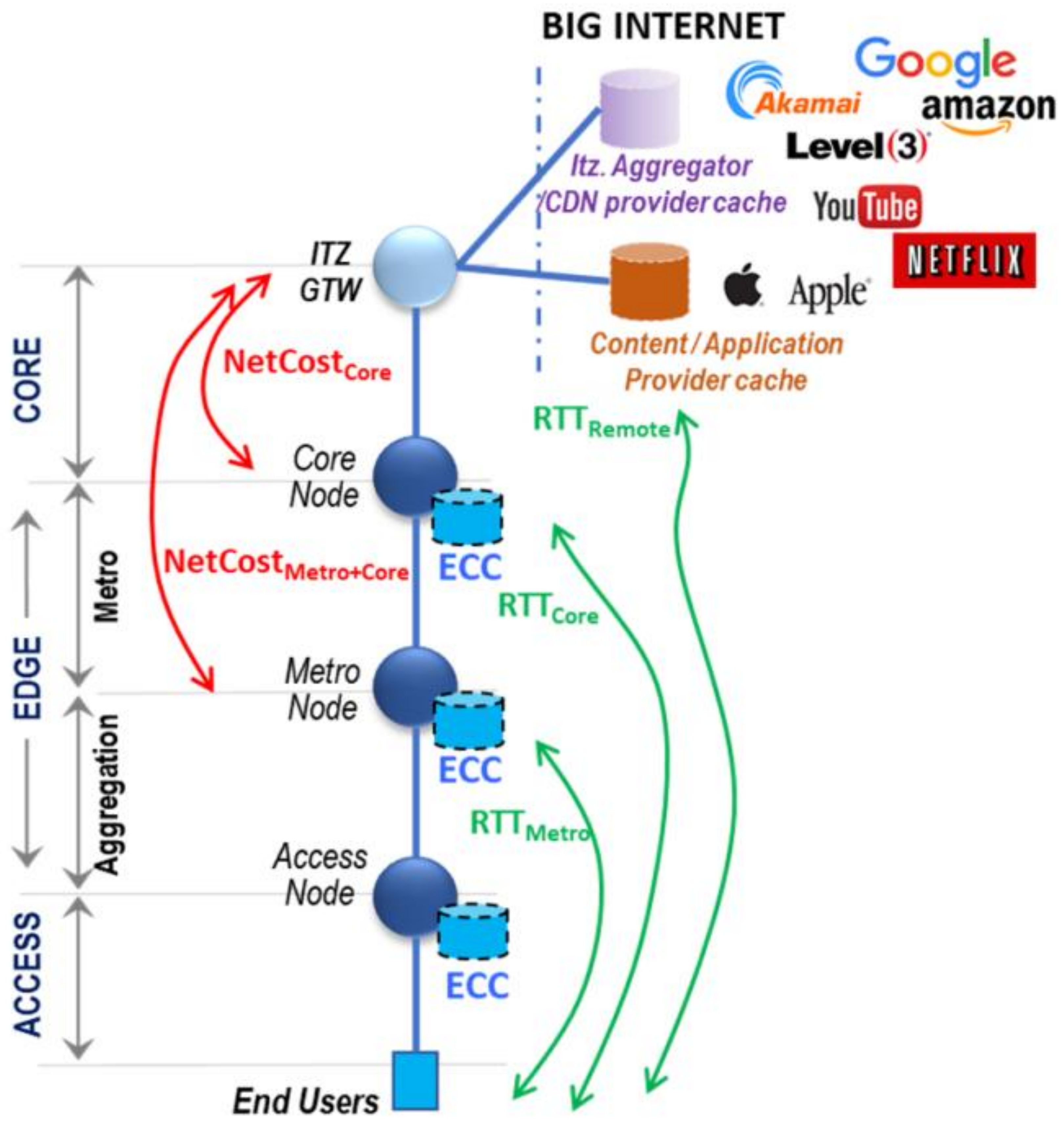
Jumyung Um et al. "Edge computing in smart production". In: Advances in Service and Industrial Robotics: Proceedings of the 28th International Conference on Robotics in AlpeAdria-Danube Region (RAAD 2019) 28. Springer, 2020, pp. 144–152.

Wenjin Yu et al. "Edge computing-assisted IoT framework with an autoencoder for fault detection in manufacturing predictive maintenance". In: IEEE Transactions on Industrial Informatics 19. 4 (2022), pp. 5701–5710.

Chaoyang Zhang and Weixi Ji. "Edge computing enabled production anomalies detection and energy-efficient production decision approach for discrete manufacturing workshops". In: IEEE Access 8 (2020), pp. 158197–158207.

Telecommunications

Compute Along the Network Hierarchy



Edge cloud computing in telecom: ECC at core, metro & access nodes

Edge Cloud Computing (ECC).

Distribute apps & content toward end-users across core, metro and access nodes. New services (4K/8K, 360° VR, autonomous driving) demand tight KPIs and lower cost.

Better KPIs Higher throughput, lower latency, less video delay — improving QoE by moving content closer.

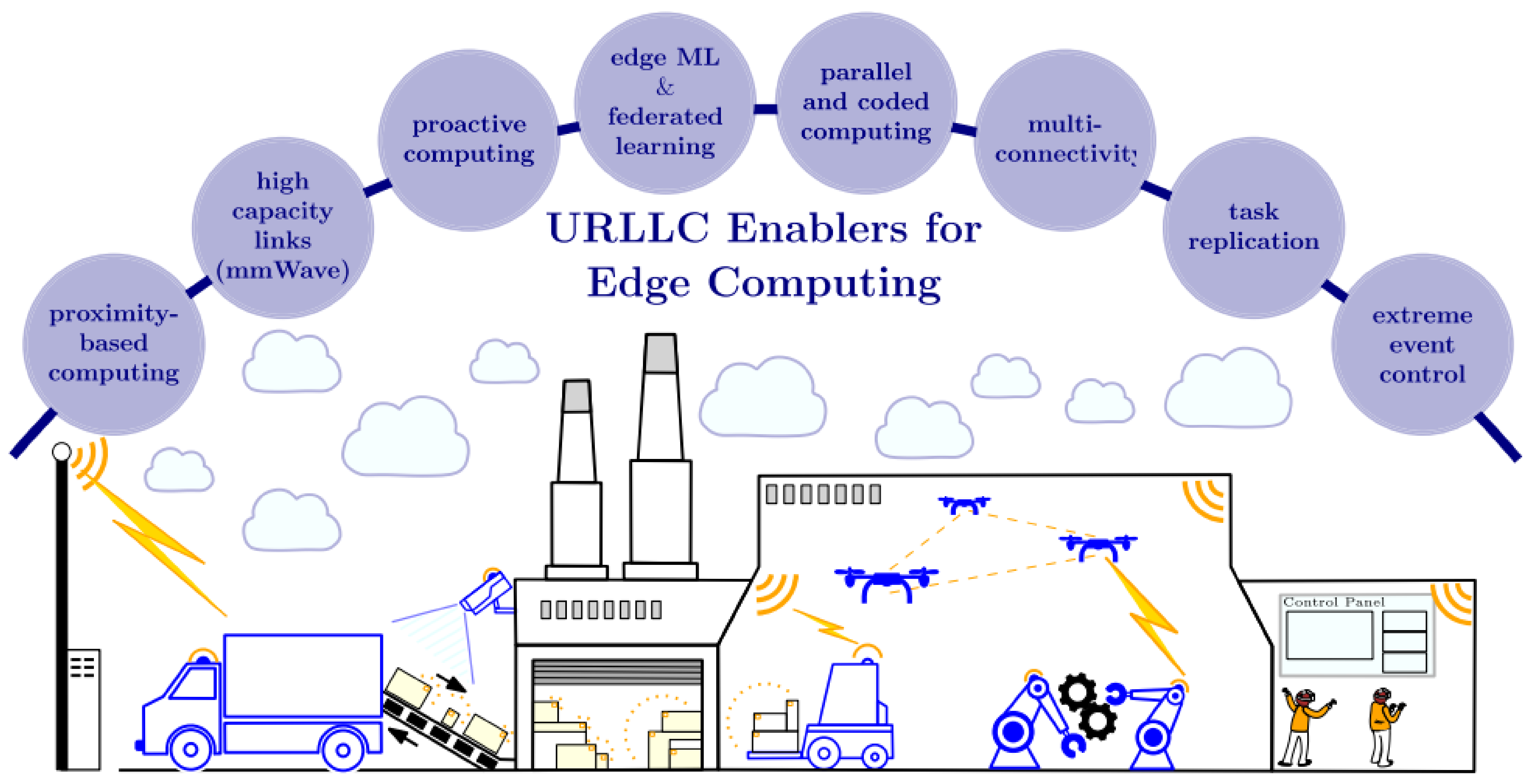
Lower TCO Offload peak traffic from the core to edge nodes, cutting total cost of ownership.

Less congestion Local delivery reduces backbone load for traditional & emerging broadband.

Gianfranco Ciccarella et al. “Edge cloud computing in telecommunications: Case studies on performance improvement and TCO saving”. In: 2019 4th International Conference on Fog and Mobile Edge Computing (FMEC). IEEE, 2019, pp. 113–120.

Telecommunications: URLLC

Ultra-reliable low-latency edge



Breakdown of key URLLC enablers for edge computing, exemplified over an Industry 4.0/Smart Factory ecosystem that includes cyber–physical systems, IoT, and MEC.

➢ Enablers

mm-wave links High-capacity millimeter-wave for huge bandwidth.

Proximity computing Process next to the user for minimal delay.

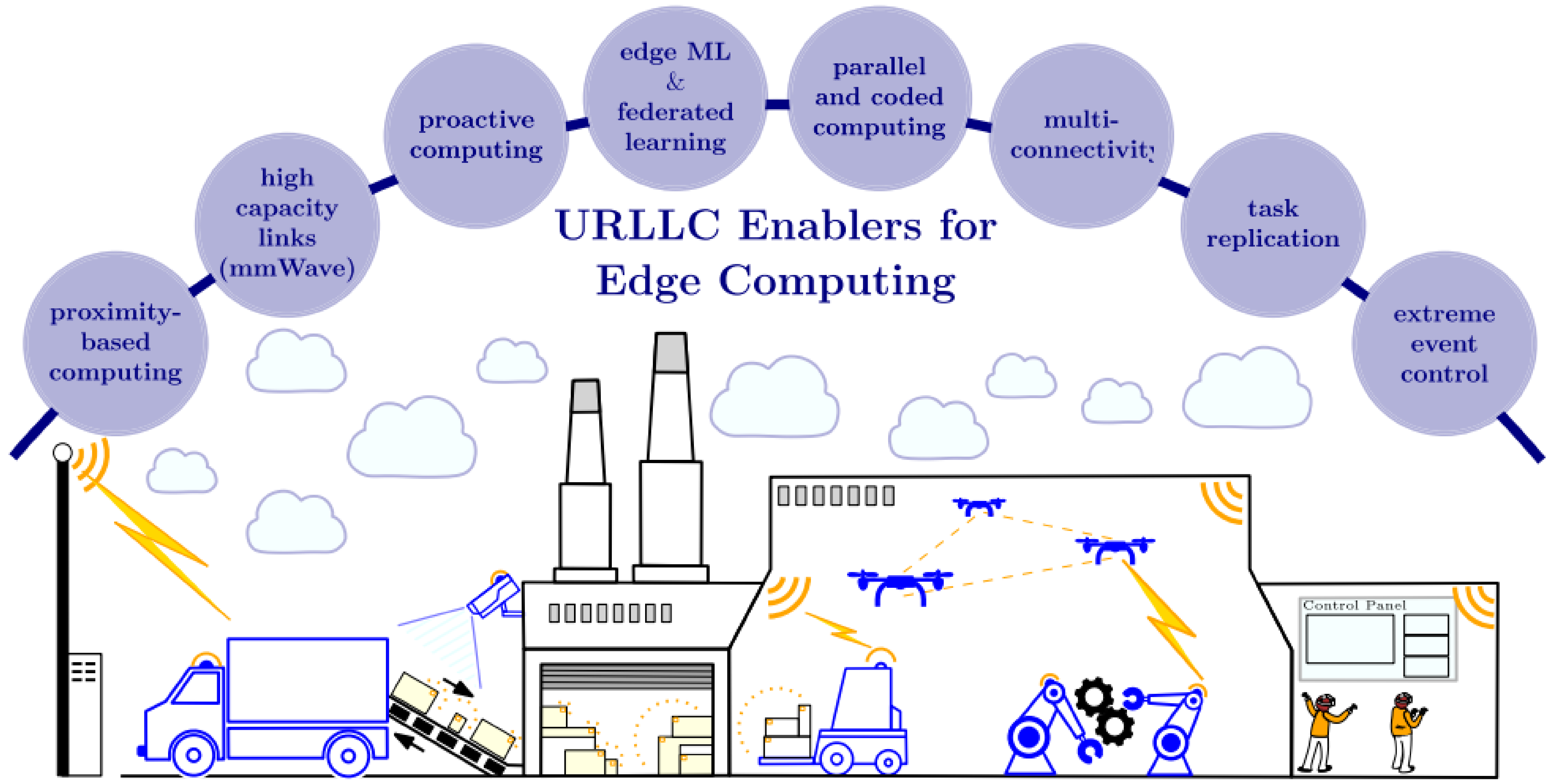
Edge ML Proactive, parallel & coded computing at the edge.

Wireless edge with latency & reliability guarantees. Centralized cloud can't meet latency-sensitive demands — a distributed edge architecture brings compute & storage to the network edge for mission-critical apps.

Mohammed S Elbamby et al. "Wireless edge computing with latency and reliability guarantees". In: Proceedings of the IEEE 107. 8 (2019), pp. 1717–1737.

Telecommunications: URLLC

Ultra-reliable low-latency edge



Breakdown of key URLLC enablers for edge computing, exemplified over an Industry 4.0/Smart Factory ecosystem that includes cyber–physical systems, IoT, and MEC.

➢ Mission-critical applications

VR / AR Immersive experiences needing tiny motion-to-photon latency.

V2X Vehicle-to-everything for safety & coordination.

Edge AI Timely, reliable inference at the network edge.

Wireless edge with latency & reliability guarantees. Centralized cloud can't meet latency-sensitive demands — a distributed edge architecture brings compute & storage to the network edge for mission-critical apps.

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Telecommunications: Challenges

Stringent KPIs
New services (4K/8K, 360° VR, AV) demand tight latency & throughput.

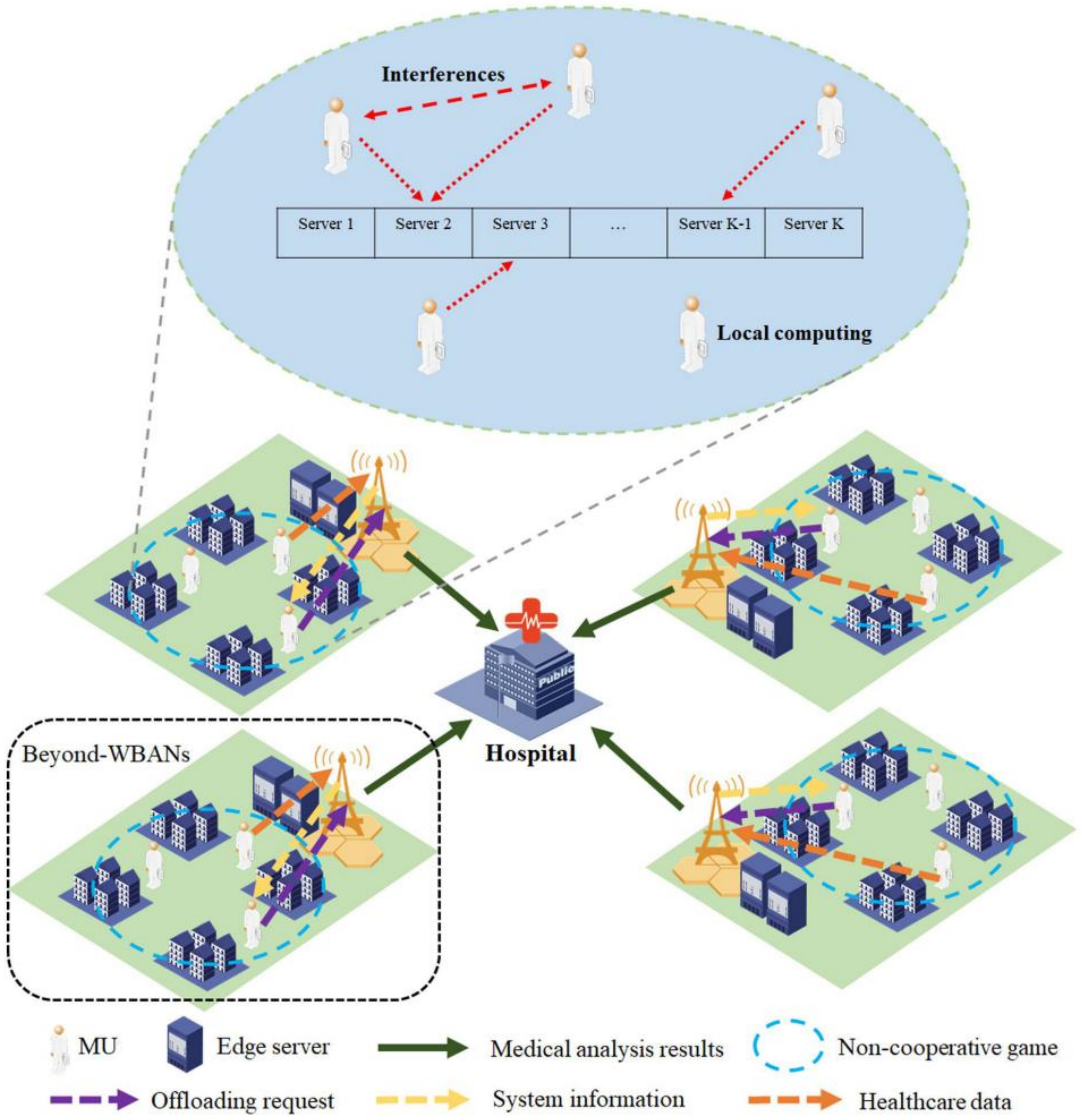
Latency + reliability
Centralized cloud can’t meet mission-critical URLLC targets.

mm-wave coverage
High-capacity links need dense, proximity-based deployment.

Cost of ownership
Balancing edge deployment against total cost of ownership.

Healthcare: IOMT

Edge computing for connected health



Edge computing in healthcare: WBANs, edge servers & the hospital

IoMT + edge.

Cloud can’t keep up with medical-device data volumes. Processing near the source cuts latency & energy and keeps sensitive data private — for responsive, efficient care.

Remote monitoring

Real-time analytics in smart-city health; wearables & remote patient monitoring.

Elderly care

RO-SmartAgeing — a six-layer IoHT stack: edge processing, fog pre-processing, cloud analytics.

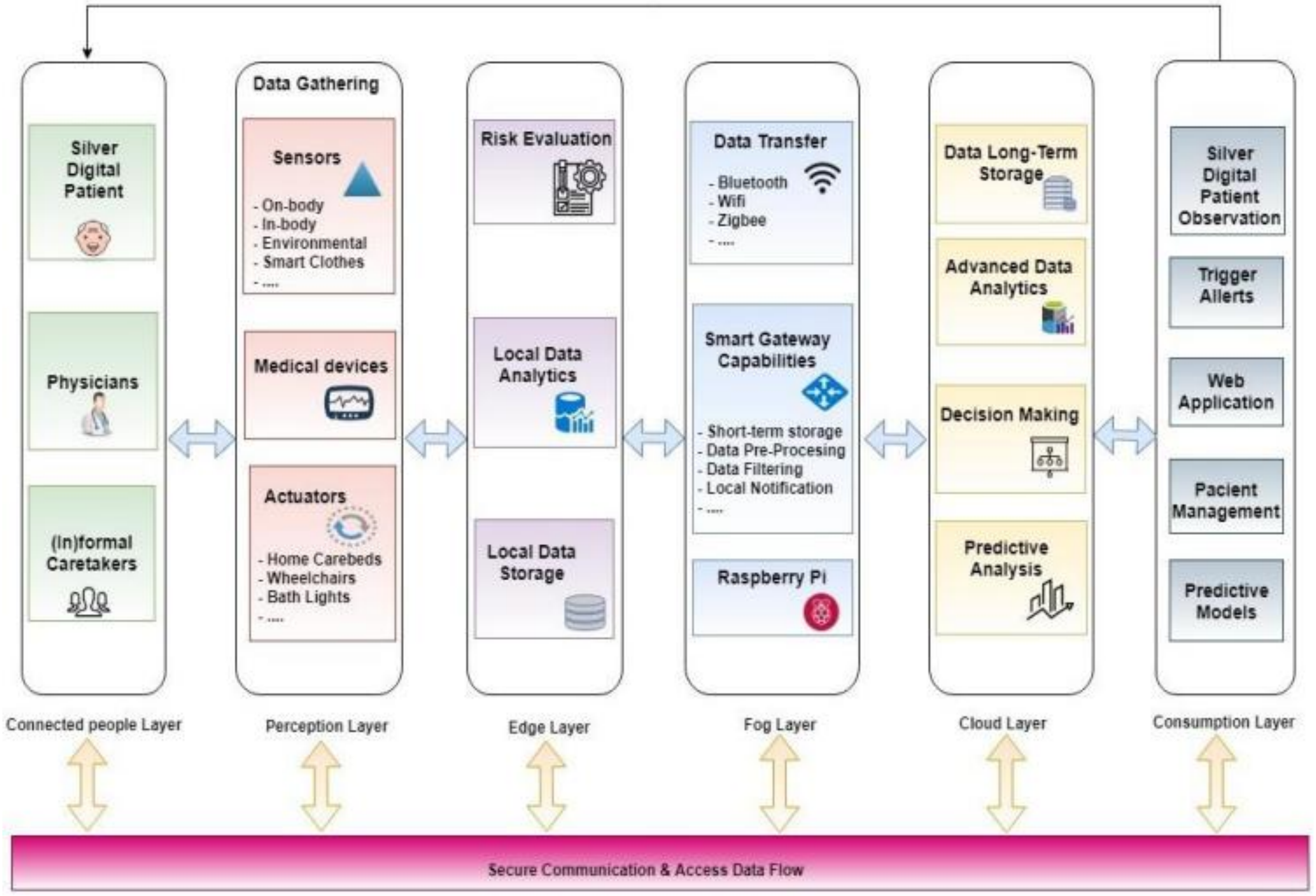
Resource games

WBAN cooperative game + beyond-WBAN offloading minimize latency & energy.

Peiran Dong et al. “Edge computing based healthcare systems: Enabling decentralized health monitoring in Internet of medical Things”. In: IEEE Network 34. 5 (2020), pp. 254–261.

Healthcare: RO-SmartAgeing

Edge computing for connected health



A proposed architecture for monitoring section of RO-Smart Ageing system

➢ Key Characteristics

IoHT + edge computing for senior monitoring to improve responsiveness of remote healthcare applications.

Uses a **six-layer architecture** with Connected People, Perception, Edge, Fog, Cloud, and Consumption layers.

The **fog layer handles preprocessing and aggregation**, while the cloud provides long-term storage, predictive analytics, and deeper decision support.

Supports **real-time health parameter** monitoring and visualization, demonstrated using pulse data.

Marilena Ianculescu et al. “IoHT and edge computing, warrants of optimal responsiveness of monitoring applications for seniors. A case study”. In: 2019 22nd International Conference on Control Systems and Computer Science (CSCS). IEEE, 2019, pp. 655–661.

Healthcare: Benefits & Privacy

Faster, safer, more private care

Real-time responsiveness

Process data at the source for timely analytics — critical for remote monitoring, telemedicine & emergencies.

Data privacy & security

Keep sensitive health data local, minimizing exposure vs. cloud storage & transmission.

Efficiency

Edge does initial processing; only critical info goes to the cloud — less load, lower energy & cost.

Future directions

Edge + AI/ML, blockchain EHRs for privacy, intelligent spectrum allocation, scalability & interoperability.

Healthcare: Challenges

Diverse sensitive data

Handling large volumes of varied, private health data.

Privacy & security

Protecting patient data across many edge devices.

Integration

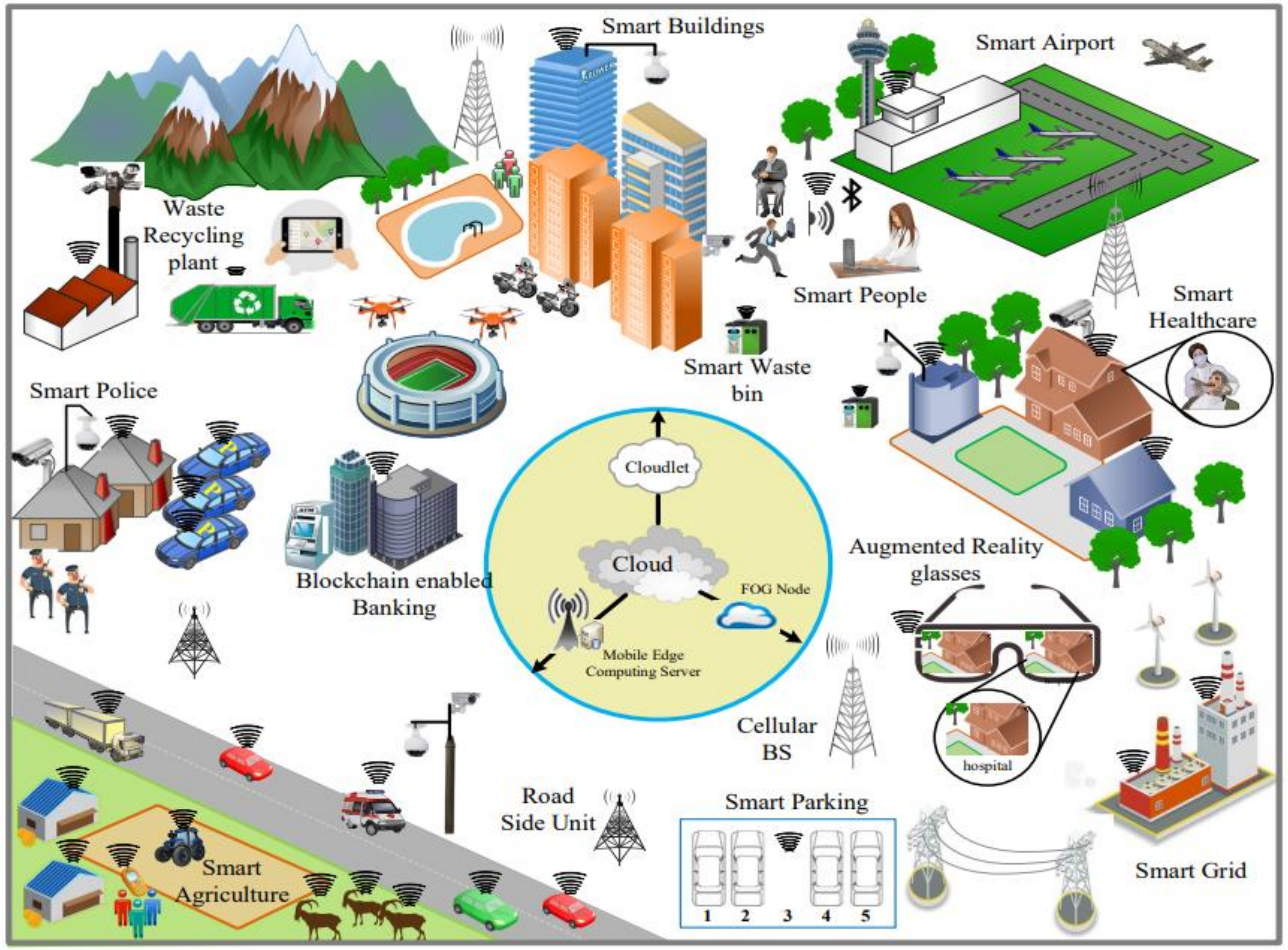
Fitting edge devices into existing healthcare infrastructure.

Energy & Age of Info

Minimizing latency, energy dissipation & data staleness.

Smart Cities

A city full of edge applications



High-level view of an IoT-based smart city

- Cities generate enormous, heterogeneous IoT data. Edge & fog process it near the source, sending only what matters upstream.

Traffic & transport Real-time monitoring, public-vehicle scheduling.

Energy & buildings Smart grids, building climate, energy scheduling.

Public safety Surveillance, situational awareness, emergencies.

Latif U Khan et al. "Edge-computing-enabled smart cities: A comprehensive survey". In: IEEE Internet of Things Journal 7. 10 (2020), pp. 10200–10232.

Smart Cities: Techniques

Four ways the edge runs the city

ADMM

Alternating Direction Method of Multipliers splits big-data work across edge servers — distributed, parallel processing that offloads the central cloud.

Situational awareness

Hossain et al. process raw IoT data at the edge into “situation images” (S-images), sending only essentials to the cloud for faster, accurate response.

YOLO + SORT

Barthélemy et al. run YOLOv3 detection + SORT tracking on smart CCTV sensors — only metadata leaves the camera, saving bandwidth & protecting privacy.

DRL & DECIoT

Liu et al. use deep RL for IoT energy scheduling; Maltezos et al. build DECIoT, a distributed edge platform for public-safety microservices.

Bin Cao et al. "Incorporating intelligence in fog computing for big data analysis in smart cities". In: IEEE Transactions on Industrial Informatics 13.5 (2017), pp. 2140–2150.

SK Alamgir Hossain et al. "Edge computing framework for enabling situation awareness in IoT based smart city". In: Journal of Parallel and Distributed Computing 122 (2018), pp. 226–237.

Johan Barthélemy et al. "Edge-computing video analytics for real-time traffic monitoring in a smart city". In: Sensors 19.9 (2019), p. 2048.

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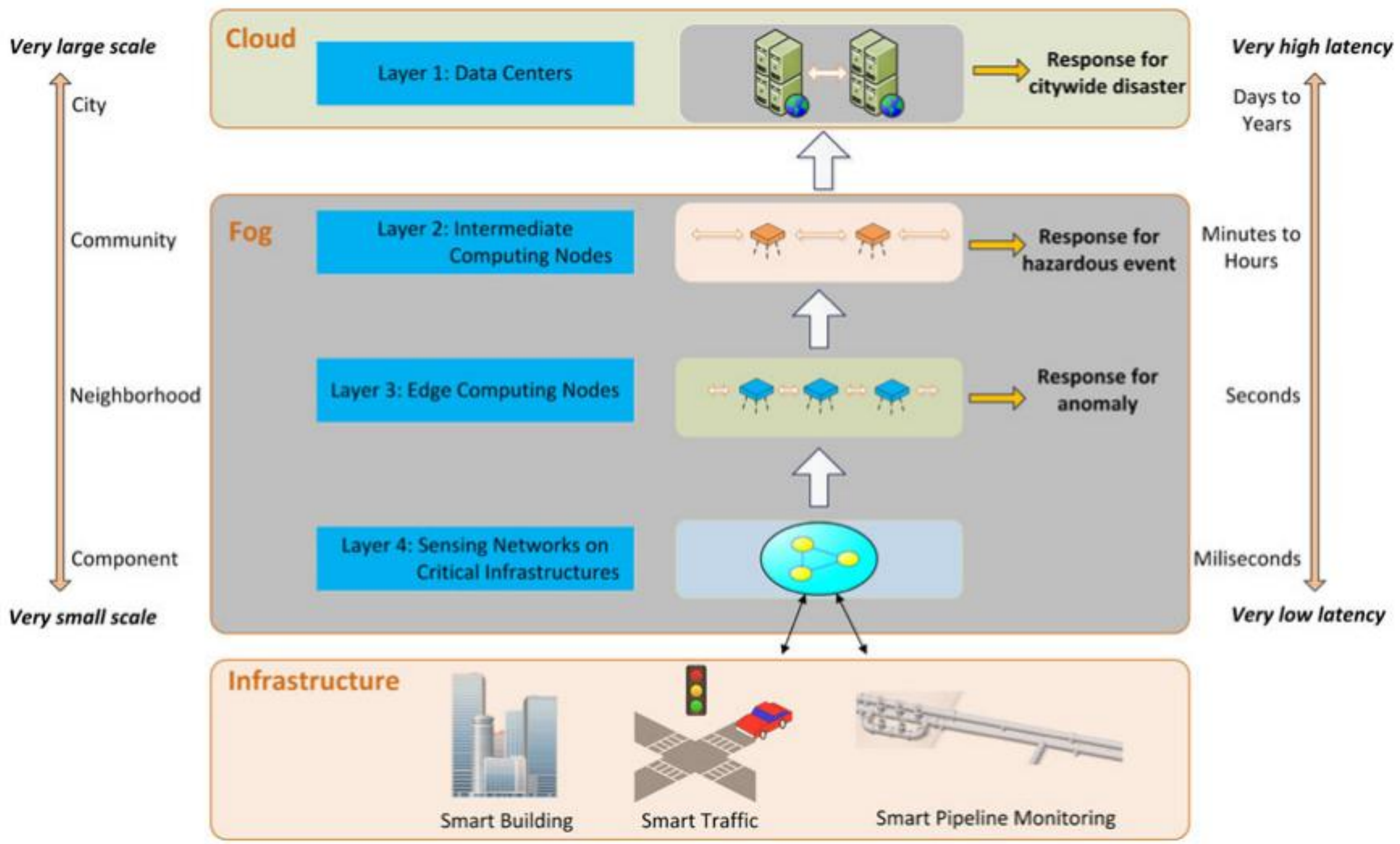
Evangelos Maltezos et al. "Public safety in smart cities under the edge computing concept". In: 2021 IEEE International Mediterranean Conference on Communications and Networking (MeditCom). IEEE. 2021, pp. 88–93.

Smart Cities: Techniques

ADMM



Four-layer Fog Computing architecture in smart cities (source)

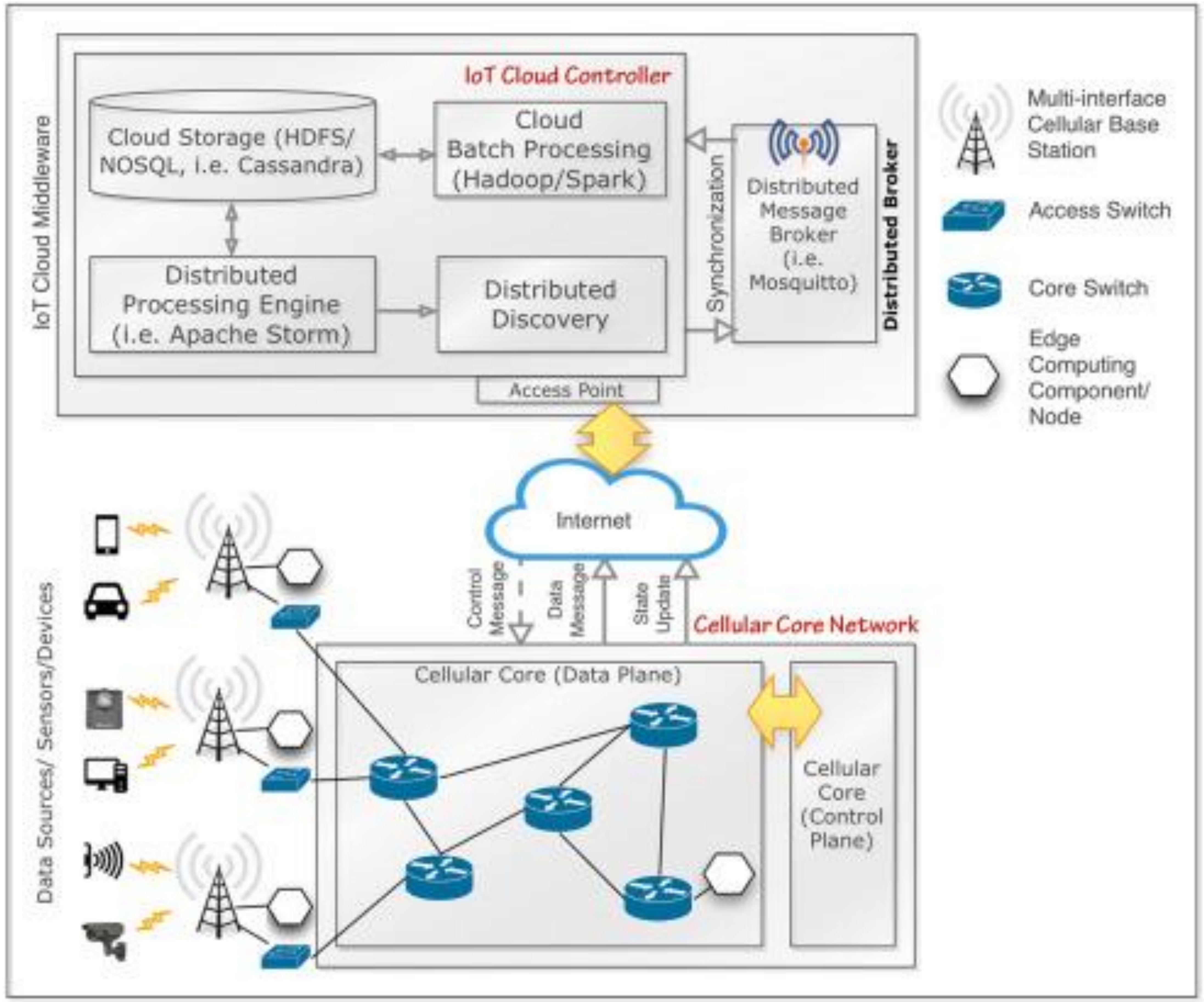
➢ Key Characteristics

- **Hierarchical fog computing architecture** distributes computation across sensing, edge, intermediate fog, and cloud layers.
- **Intelligence is pushed toward** the edge for feature extraction, anomaly detection, event recognition, and fast local control.
- Uses a **smart pipeline monitoring case study** with fiber-optic sensors and machine learning.
- Greatly reduces communication overhead by sending only high-level features; transmitted data can be **about 0.02% of the raw data size.**

Bin Cao et al. "Incorporating intelligence in fog computing for big data analysis in smart cities". In: IEEE Transactions on Industrial Informatics 13.5 (2017), pp. 2140–2150.

Smart Cities: Techniques

Situational awareness



Situational awareness (source)

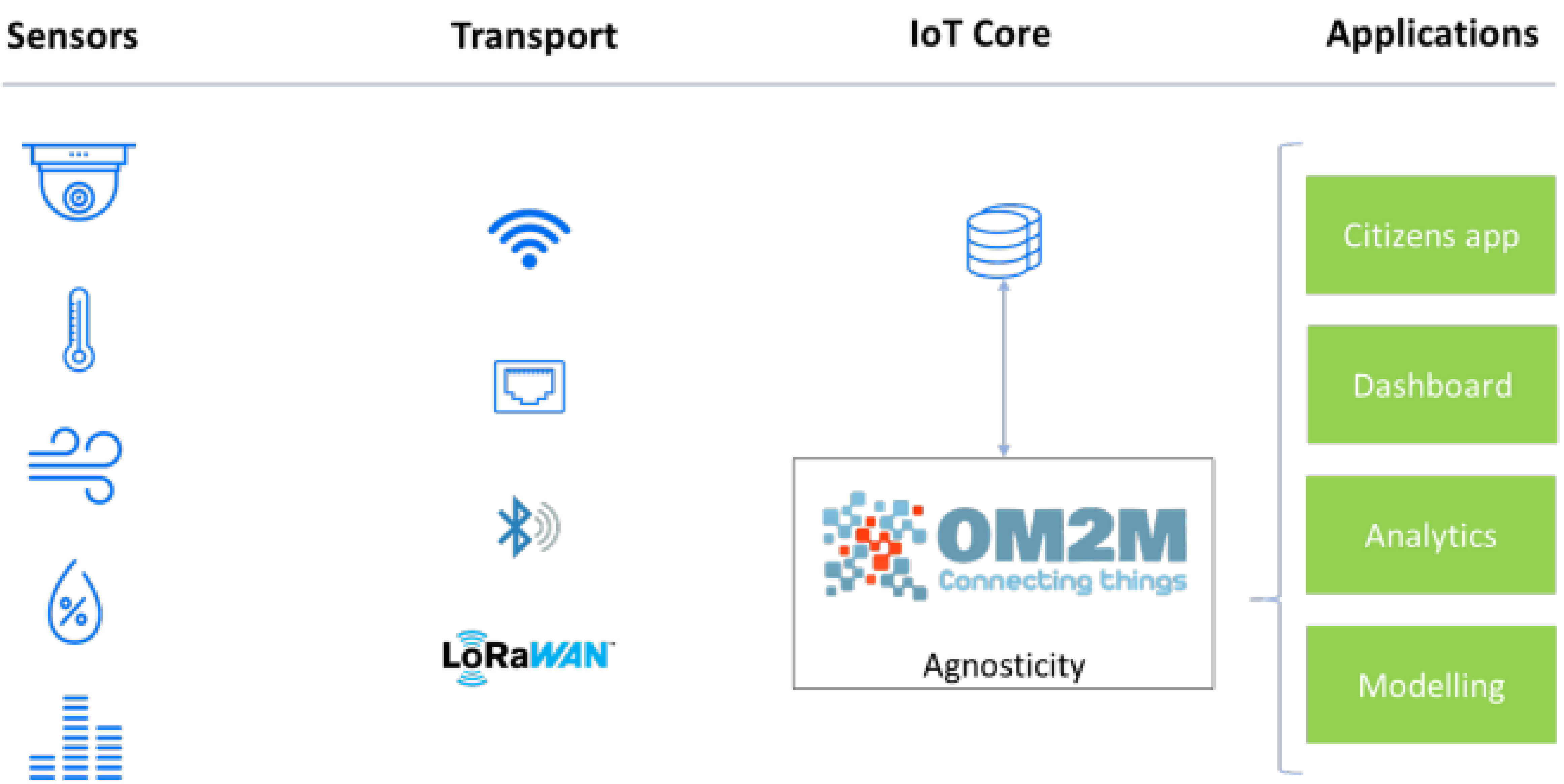
➢ Key Characteristics

- **Edge-based IoT data processing** moves computation closer to heterogeneous smart-city sensors instead of sending all raw data to the cloud.
- **Focuses on situation awareness,** converting low-level IoT observations into higher-level information for city decision-makers.
- Introduces a **situation image (s-image)** to represent and identify the current situation.
- Uses a **four-part architecture with Device Module**, Edge Network, IoT Cloud Middleware, and Subscribers.

SK Alamgir Hossain et al. "Edge computing framework for enabling situation awareness in IoT based smart city". In: Journal of Parallel and Distributed Computing 122 (2018), pp. 226–237.

Smart Cities: Techniques

YOLO + Sort



YOLO + SORT (source)

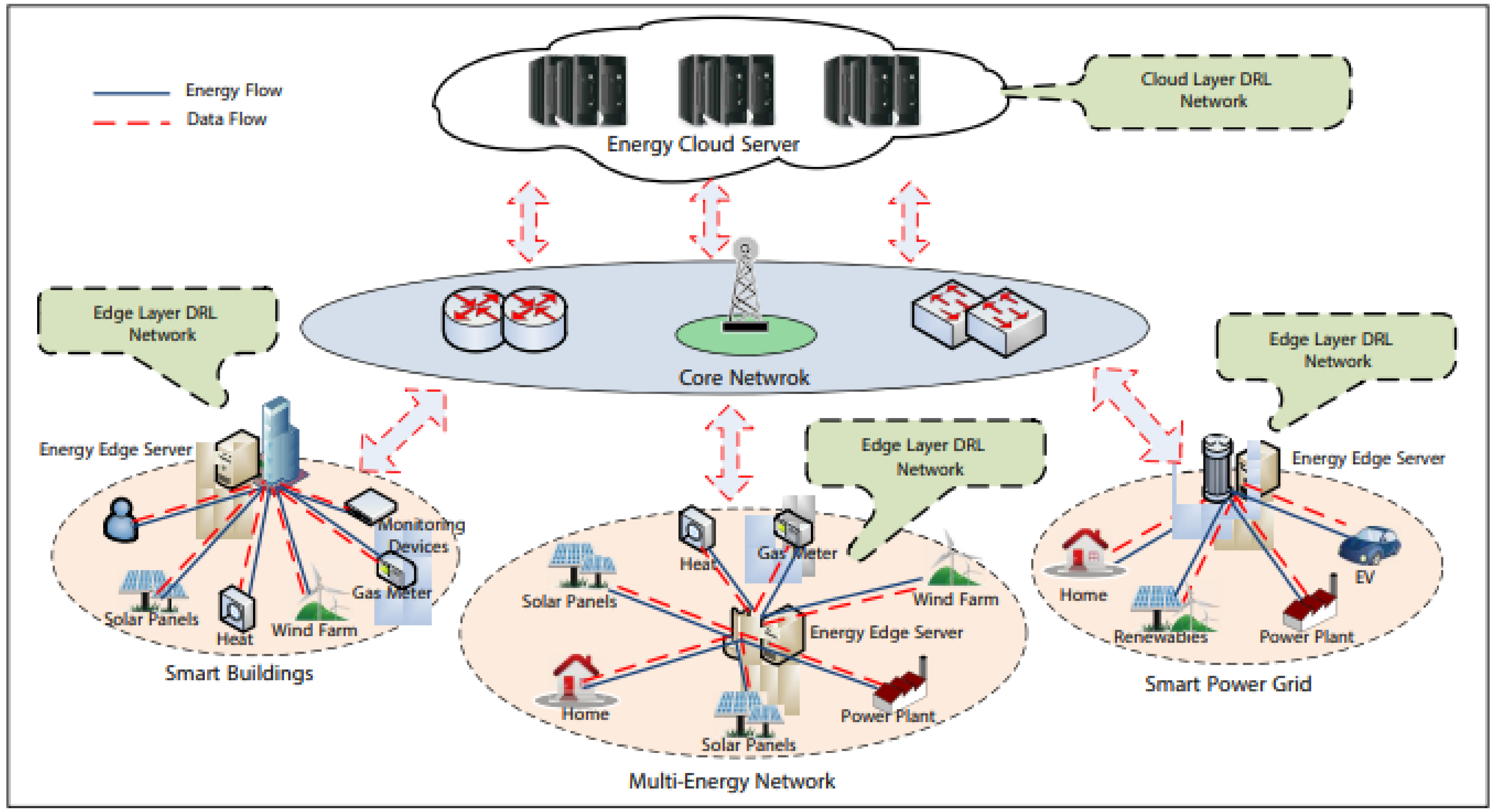
➢ **Key Characteristics**

- **Edge-based video analytics** processes CCTV streams locally instead of sending raw video to the cloud.
- **Performs real-time multimodal traffic monitoring** for vehicles, pedestrians, and cyclists.
- Combines **YOLOv3 for object detection with SORT** for real-time tracking.
- Introduces the **Agnosticity framework for interoperable** collection, storage, and access of data from multiple sensors.

Johan Barthélemy et al. "Edge-computing video analytics for real-time traffic monitoring in a smart city". In: Sensors 19.9 (2019), p. 2048.

Smart Cities: Techniques

Energy management for smart cities



The IoT-based energy management architecture for smart cities (source)

➢ Key Characteristics

- **IoT + edge computing + deep reinforcement learning** for intelligent energy management in smart cities.
- **Proposes a four-layer software model** with sensing, network, cognition, and application layers.
- Introduces **Edge DRL and Cooperative DRL** scheduling methods for optimizing energy use.
- Achieves **lower energy cost and lower delay** than traditional cloud-only scheduling.

Yi Liu et al. "Intelligent edge computing for IoT-based energy management in smart cities". In: IEEE Network 33.2 (2019), pp. 111–117.

Smart Cities: Challenges

Heterogeneous sources

Fusing data from many diverse city sensors in real time.

Data privacy

Protecting citizen data across a distributed edge.

Resource allocation

Balancing workloads, energy & fairness among fog nodes.

Fault tolerance

Adaptive, resilient control despite failures & disturbances.

Summary

- In manufacturing domain, a four-domain architecture enables predictive maintenance & LSTM/autoencoder anomaly detection — cutting network load and downtime.
- In telecommunications, edge cloud computing improves KPIs & TCO; URLLC with mm-wave enables VR, V2X and edge AI.
- In healthcare, IoMT + edge delivers real-time remote monitoring and elderly care, while keeping health data private.
- In smart cities, ADMM, situational awareness, YOLO+SORT, DRL and DECIoT power traffic, energy and public-safety services.

Practice

1. How does edge computing improve operational efficiency in the manufacturing sector?
2. Describe the role of edge computing in enhancing real-time patient monitoring and diagnostics in healthcare.
3. How does edge computing support the deployment and efficiency of 5G networks in the telecommunications industry?
4. Discuss the impact of edge computing on public safety and resource management in smart cities.
5. How does edge computing facilitate predictive maintenance in manufacturing environments?

Project

Analyze and present a case study of a successful edge computing implementation in a specific industry.

How to plan it

1. **Pick an industry & case** Choose a real deployment — a smart factory, a telecom operator, a hospital, a smart-city pilot.
2. **State the problem** What did cloud-only fail at — latency, bandwidth, privacy, reliability?
3. **Map the architecture** Show the edge design: devices, edge nodes, network, cloud, and the data flow.
4. **Report the outcomes** Quantify the gains (latency, cost, accuracy) and name the remaining challenges.

Example cases to start from

- **Manufacturing** Chen et al. — smart factory that cut network load 60%.
- **Telecom** Ciccarella et al. — ECC improving KPIs & saving TCO.
- **Healthcare** RO-SmartAgeing— six-layer IoHT senior monitoring.
- **Smart city** Barthélemy et al. [7] — YOLO+SORT traffic pilot, Liverpool NSW.

Deliverable: a short report + presentation — problem, edge architecture diagram, measured results, and lessons learned vs. a cloud-only baseline.

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