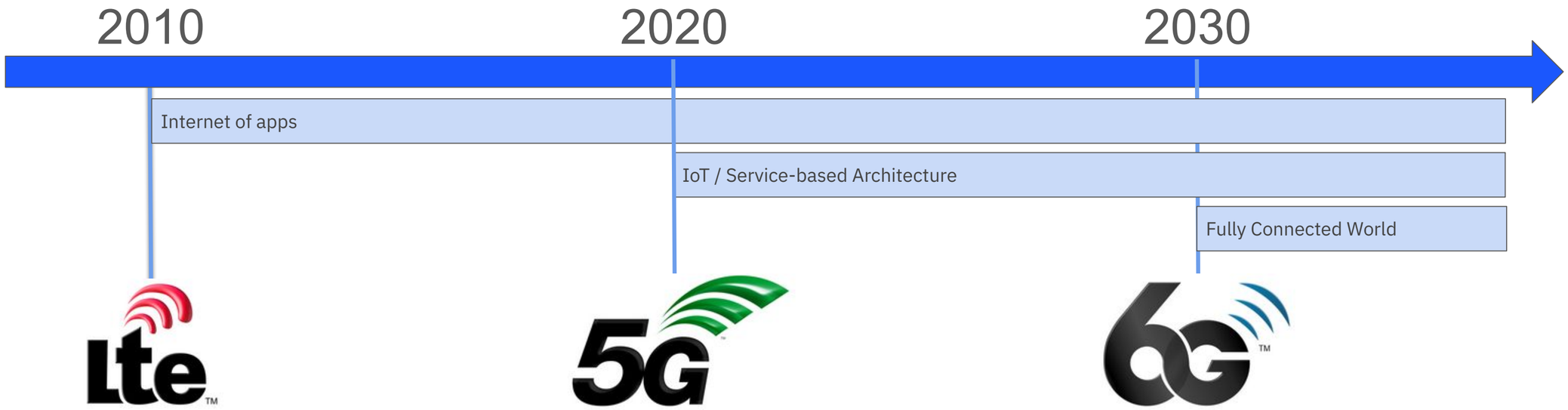
From network digital twins to network of networks: enabling fully autonomous 6G systems

ubiwhere

Context and Motivation



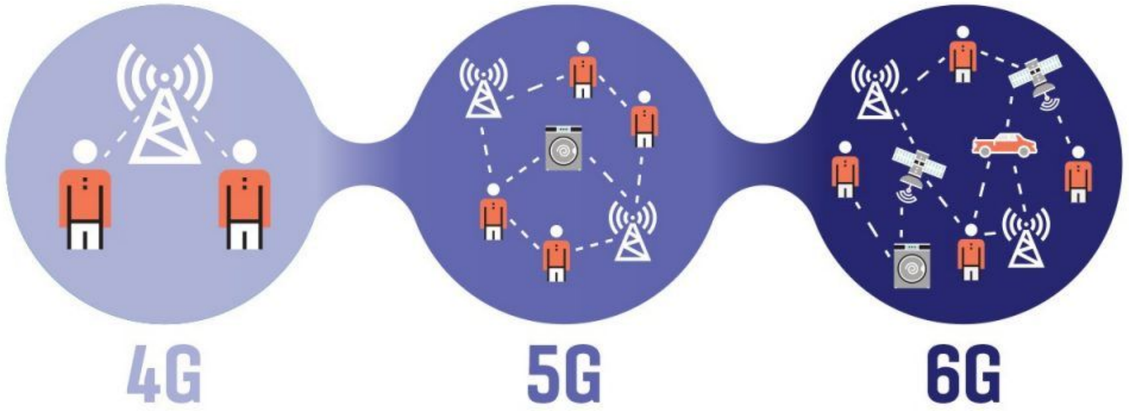
- Higher data rates, high efficiency and low latency
- MIMO, CA, SON

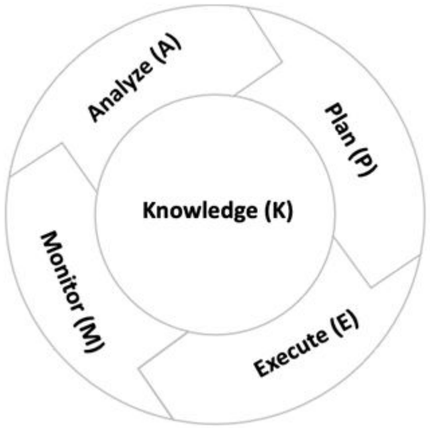
- Network slicing
- Service Based Architecture
- Internet of Things
- eMMB, URLLC, mMTC

- Ubiquitous Coverage
- Network simplification
- Sustainable IoE
- TN/NTN, RIS, AI/ML, ISAC, Edge Computing, Massive MIMO

Context and Motivation

- Each new capability increases not just traffic, but interdependencies between systems
- Higher demand for network management operations
  - Impacts performance and efficiency of decision-making
- Performance, sustainability, and resilience are now tightly coupled





- Human-in-the-loop becomes human-as-bottleneck in ultra-dense, software-defined environments.
- Manual configuration is no longer an option – autonomous networks is the only way forward

Network Digital Twins

Digital Twins - Foundations

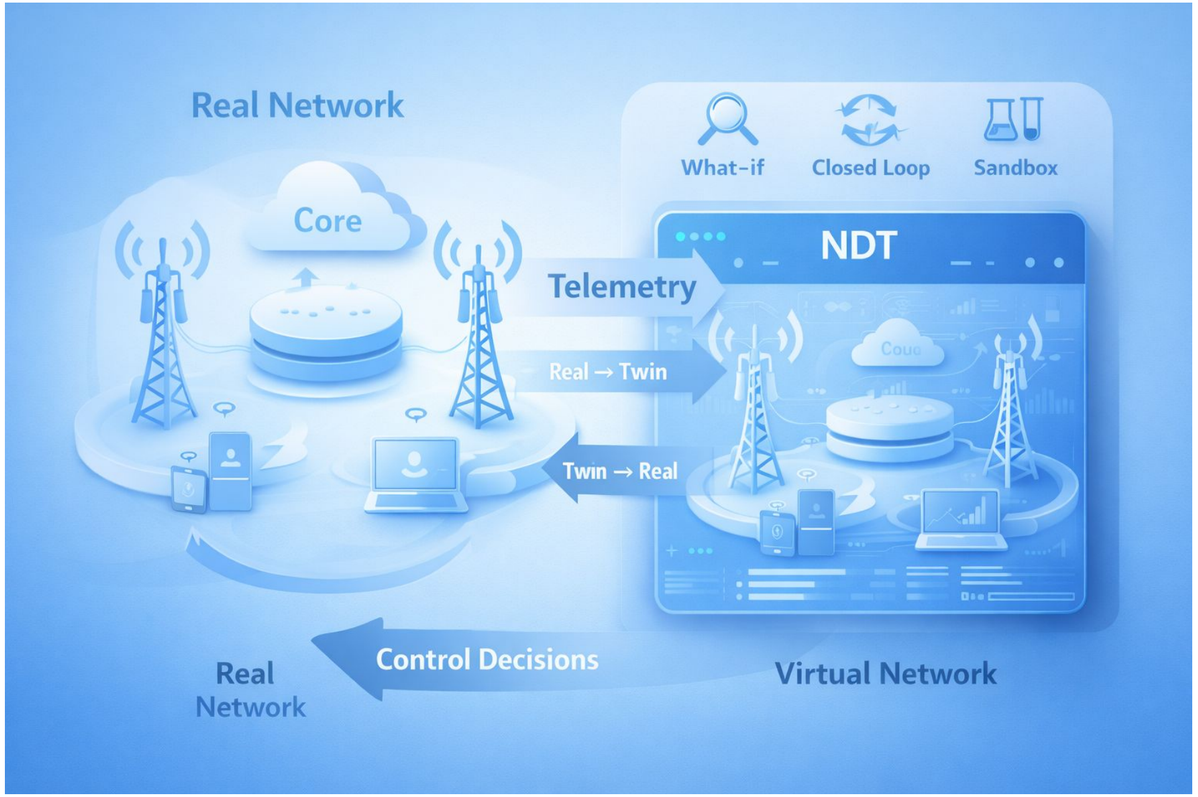
- What is a Digital Twin? – Virtual replica of the real-world state of a physical device
  - Real-time monitoring, simulation and predictive analytics to improve performance and efficiency

- Digital Twins have evolved
  - Static representation via data collection
  - Live synchronisation through real-time data streams
  - Enhancing with AI capabilities for better predictions and anticipation of future states

Digital Twins – Network Digital Twins

- Network Digital Twins – real-time digital replica of the physical network (Core Network, RAN, Edge, Cloud)
  - what-if analysis
  - closed loop optimisation
  - network simulator/sandbox

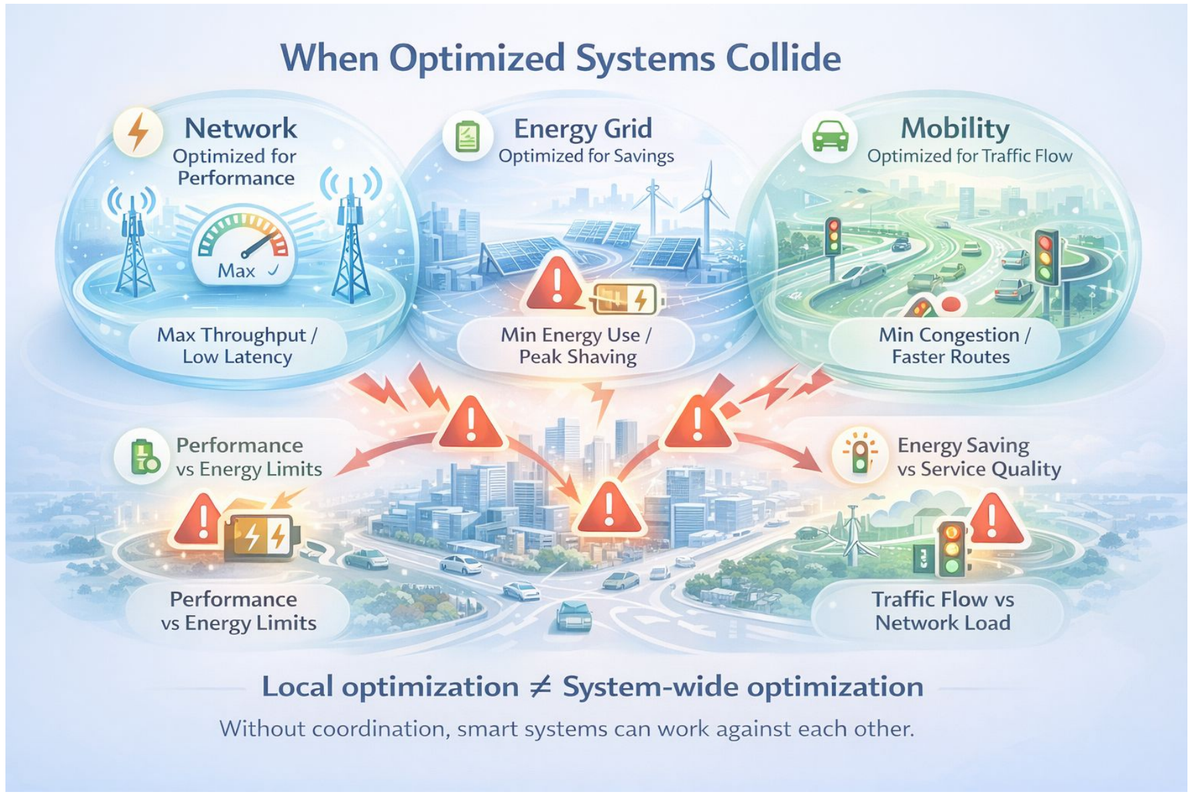
- Improved network planning, network optimisation, automated lifecycle management, fault prediction
- Leverage AI/ML tools to enhance prediction and simulation
  - Improved precision and control
  - Reduce latency of decision making



Why Network Digital Twins are not enough

- In a shared 6G environment, network optimisation might conflict with global scenarios that connect other essential verticals
  - Energy grid
  - Mobility
  - Disaster scenarios

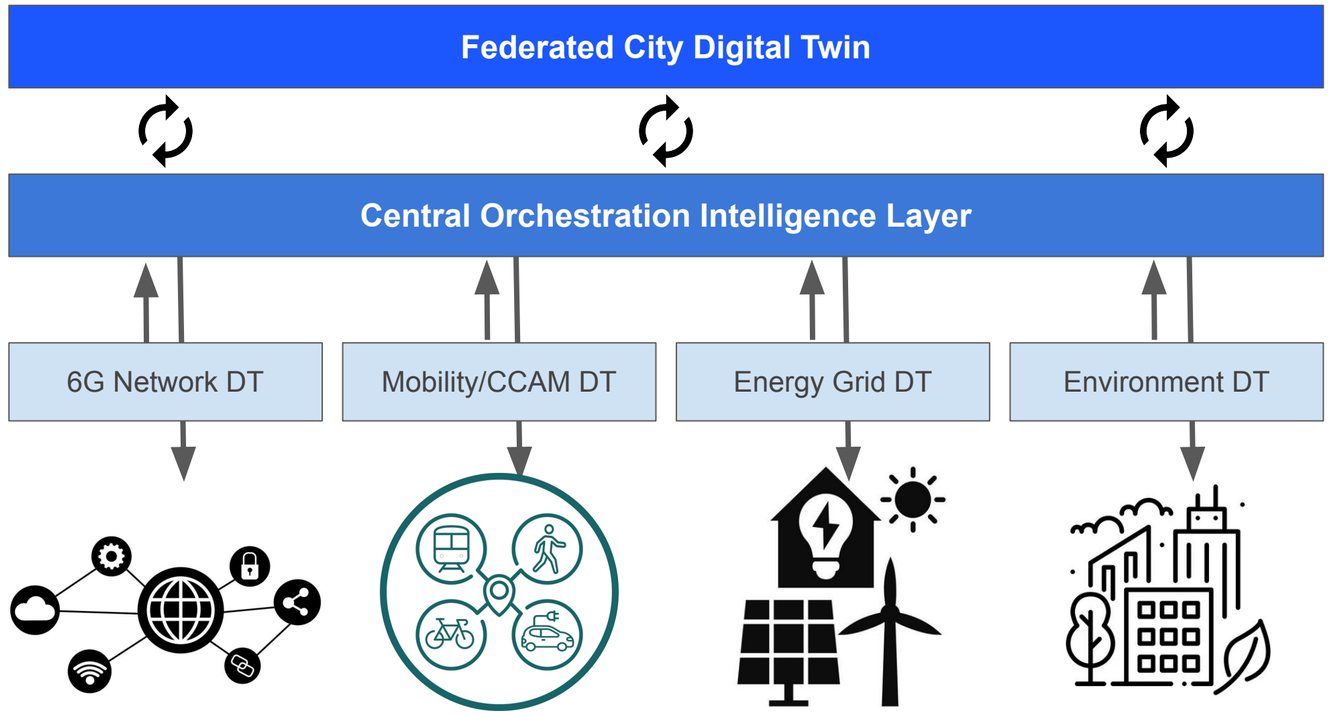
- NDT requires context beyond networks to correctly anticipate the cascading effects of occurrences in different domains
  - Safety and environmental Data
  - Socioeconomic and Administrative Data
  - Infrastructure Data
  - Domain-specific operational data



Network of Networks

Network of Networks

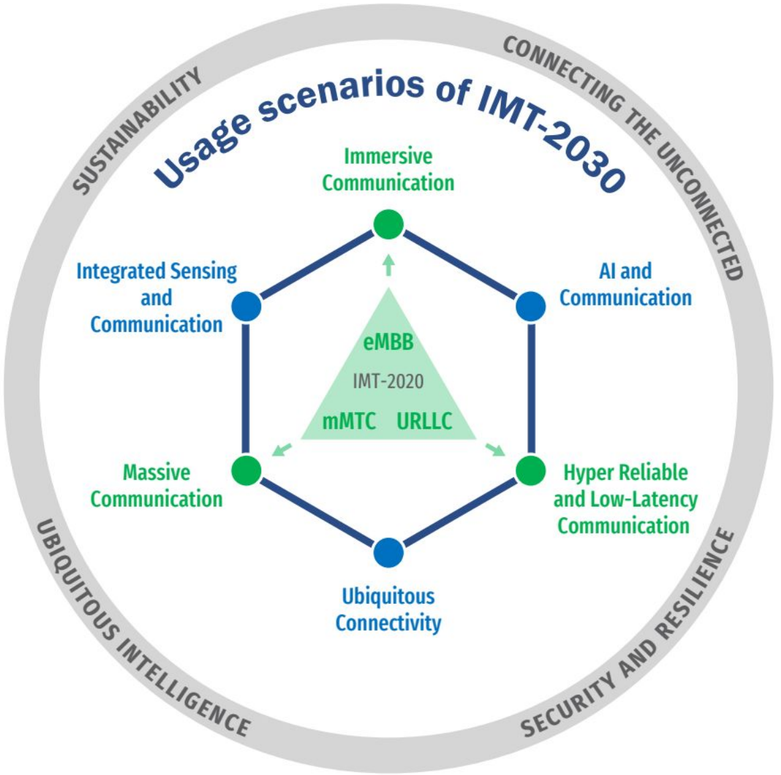
- NoN paradigm - shifting traditional network architecture towards a unified ecosystem of diverse subnetworks
- Different subnetworks have different requirements
  - Latency, data throughput rates, connectivity uptime
- NoN introduces cross-domain observability and policy-aware decision-making across multiple domains, allowing for multi-objective optimisation



Putting it all together

- Key building blocks for future 6G systems
  - Domain-specific digital twins, enhanced with AI/ML for prediction, control and reasoning
  - Intent based and Closed-loop orchestration for automated lifecycle system management
  - Robust and well defined set of trust, safety and governance policies
  - Supporting control hierarchy, allowing human and AI to oversee at both a local and global level

- Autonomy is not just automation, but also governed intelligence

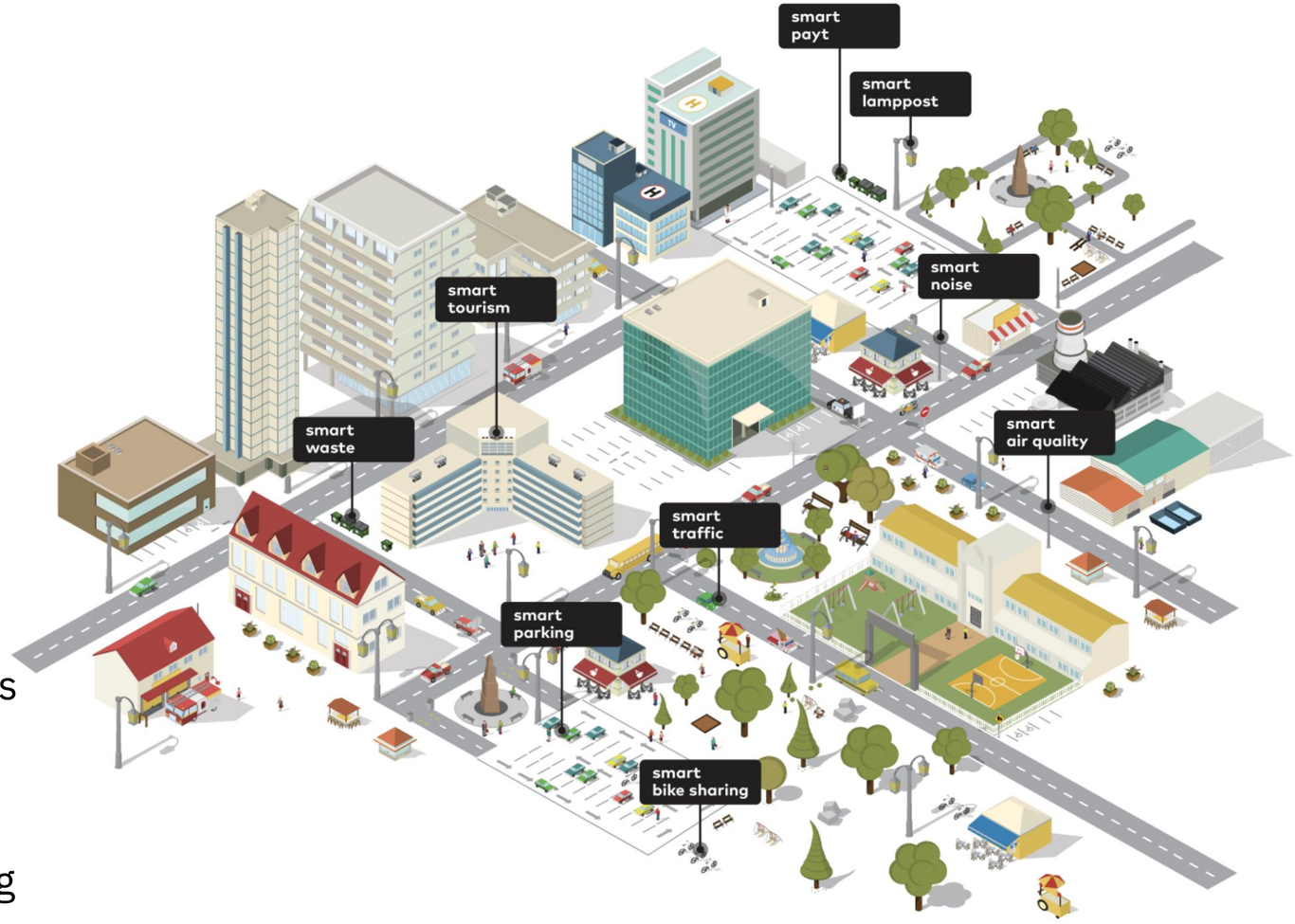


Cities as Networks of Networks

Urban Network of Networks

- Multi-domain Urban environment
  - Mobility sensors
  - Energy grid sensors
  - Environmental sensors
  - Public service feedback and management
  - Telecommunications connecting city actors

- Cities are the first real-world system-of-systems laboratories, and the best integration platform for developing and testing 6G technologies



Urban Platform

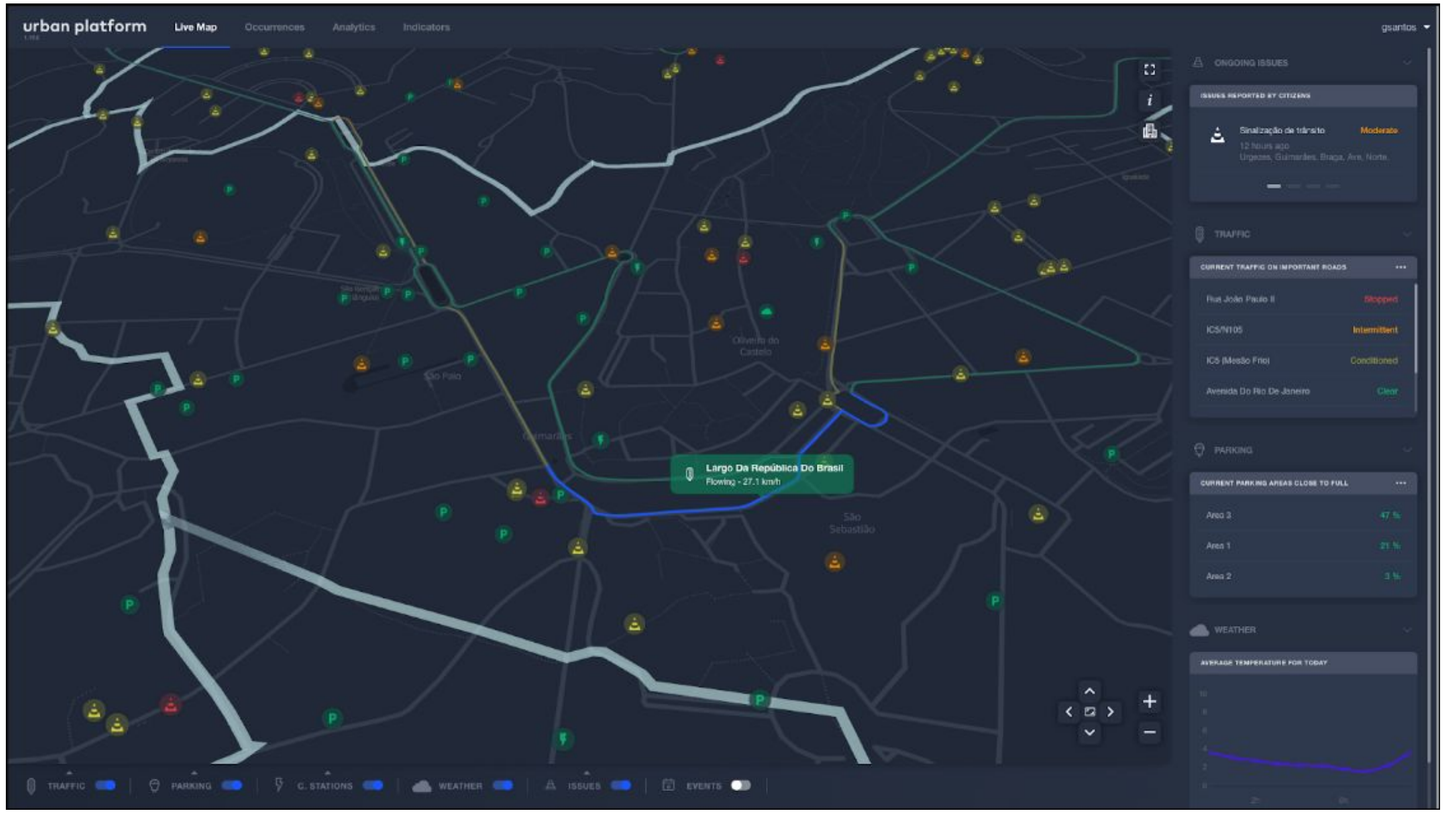
Digital solution for a unified vision of the city, through the integration of data from different domains and the interoperability of information systems.

- State of the city in real time;
- Integration and harmonization of data;
- Interaction with citizens;
- City indicators;
- Availability of open data;
- Urban intelligence.

Urban platform – bridging NDT and NoN

- Urban Platform acts as a Central Intelligence Layer
  - Domain-specific digital twins can be separated through different governance layers
  - Orchestrated by a shared federated environment

- Municipalities can access their own tailored view
  - Statistical data is supported by AI/ML tools for enhanced interpretability by local users



Use case #1: Cascading effects of a disaster scenario

(Example: earthquake, flood, urban fire incident)

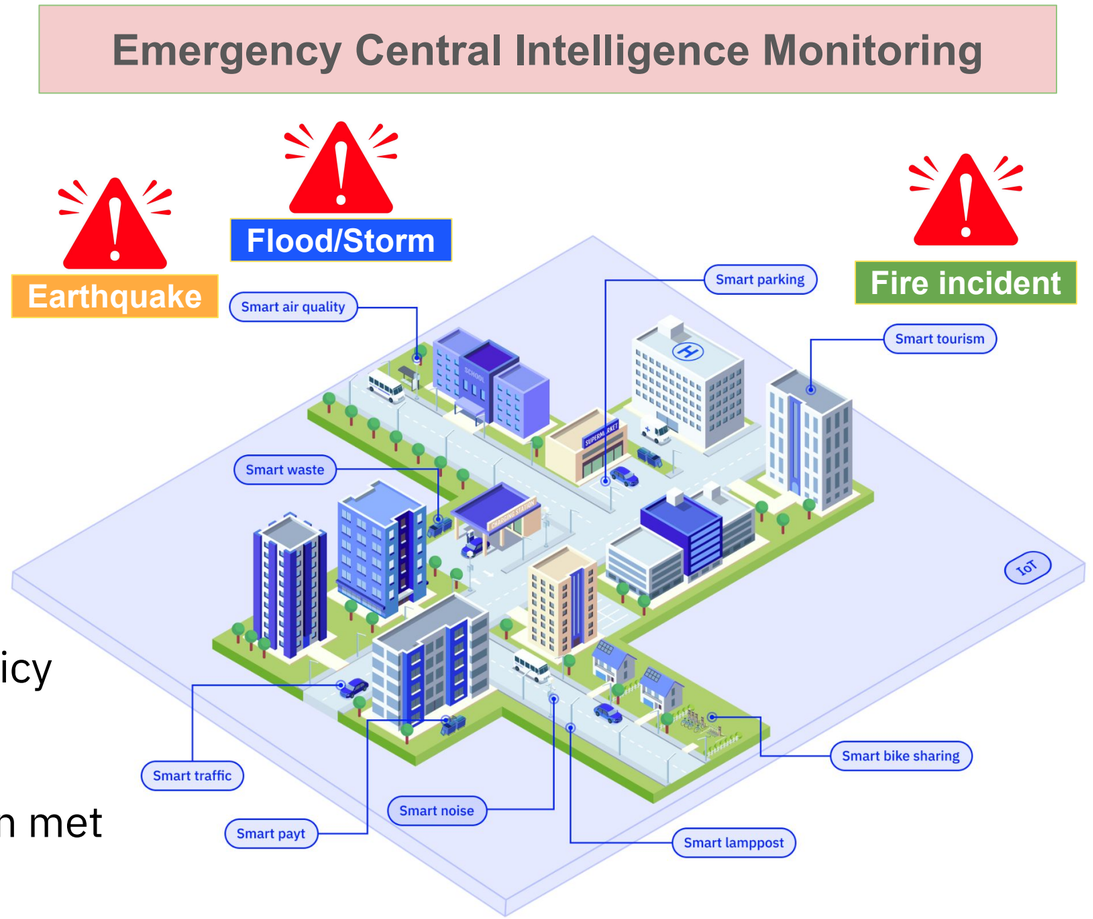
Potential domains affected:

- Energy (power outage)
- Telecommunications (cell congestion/site failures)
- Mobility (road blockages)
- Public services (congestion of emergency services)

Infrastructure failures propagate faster than humans can coordinate responses.

UBP as a City Digital Twin:

- Cross-domain to observability and assessment
- Leverage Digital Twin and AI/ML to update system policy (what to optimise in this scenario)
- Act cross-domain according to the best solution
- Run verification checks and loop until criteria has been met



Use case #2: Sustainability of City Verticals

(Example: Energy, Mobility, BIM, Telecommunications)

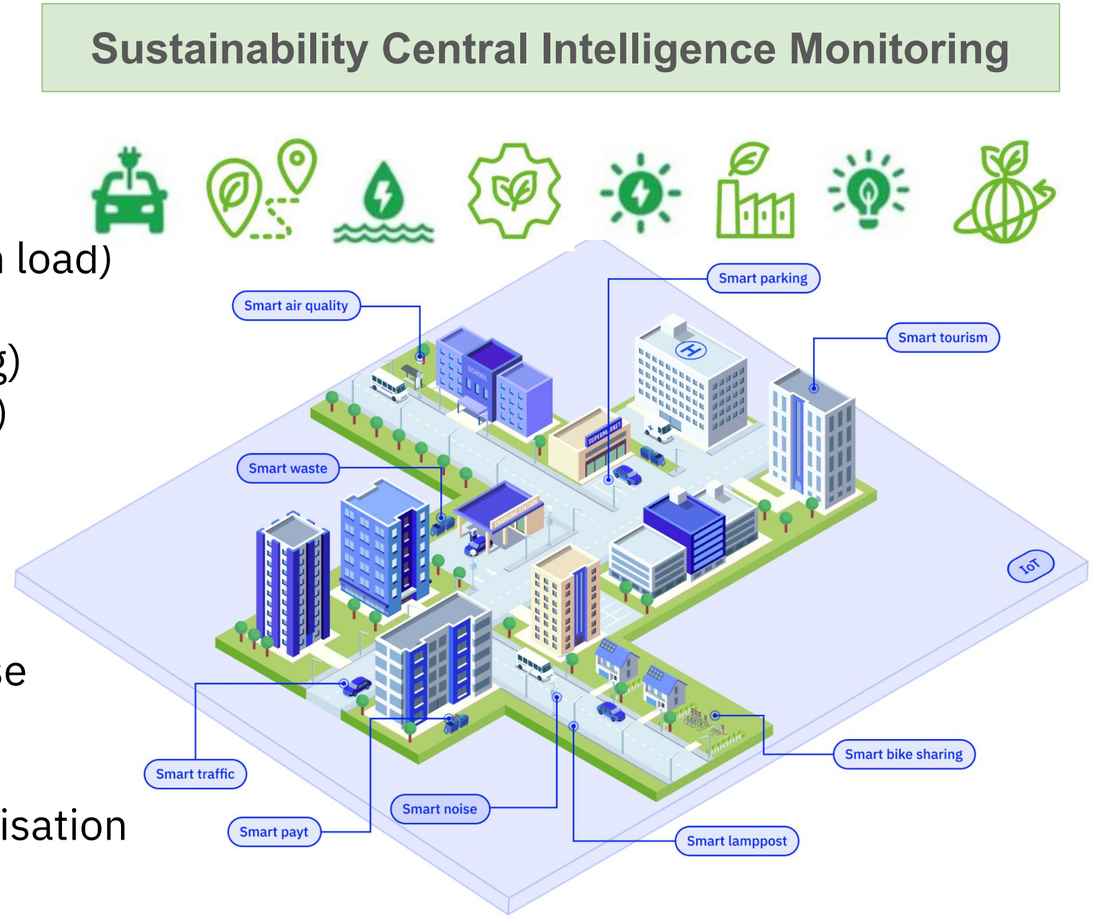
Domains continuously optimised:

- Energy grid (Green energy production, EV use, telecom load)
- Mobility (Emission and traffic monitoring, congestion)
- Telecommunications (Edge network load for offloading)
- BIM (HVAC demand, building occupancy, grid demand)

The city is continuously monitored as a living system with energy, traffic, and digital load signals.

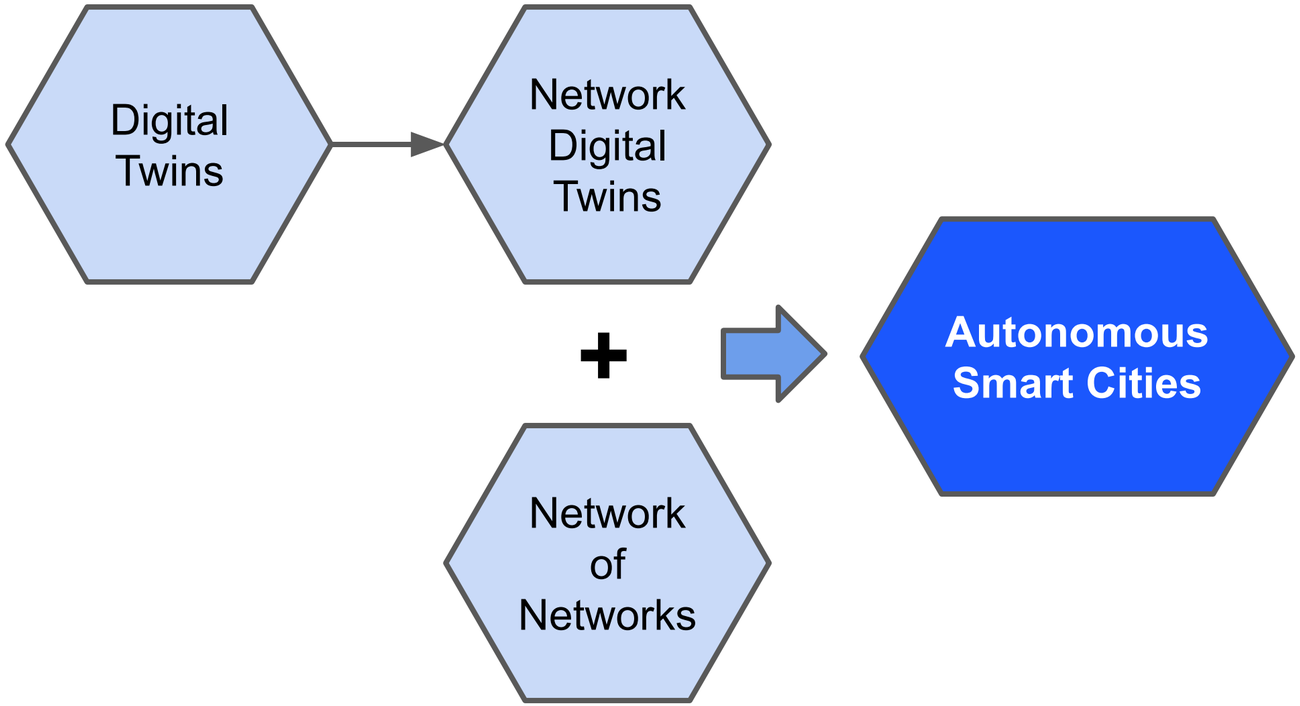
UBP as a Sustainable Digital Twin:

- Observe cross-domain sustainability metrics
- DT + AI/ML with sustainability policy such as “Maximise renewable energy usage while maintaining QoS”
- Act across urban domains
- Verify current status according to policy and run optimisation loop



Key takeaways

- Digital Twins allowing for what-if simulation of complex systems
- NDTs as starting points for Network optimisation, but not enough for the global environment
- NoN is the orchestration paradigm aligned with the future 6G networks
- Urban environment serves as the best benchmark for testing 6G use cases
  - UBP as Ubiwhere's enabler to test these tools and technologies



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