Hexa-X Demo #3: FLEX-TOP

Flexible topologies for efficient network expansion and complementary means for global coverage, sustainability and trust

WINGS

P. Vlacheas, P. Demestichas,

V. Tsekenis, S. Barmpounakis

Hexa-X

hexa-x.eu

Starting point

Management – Decisions - Actions

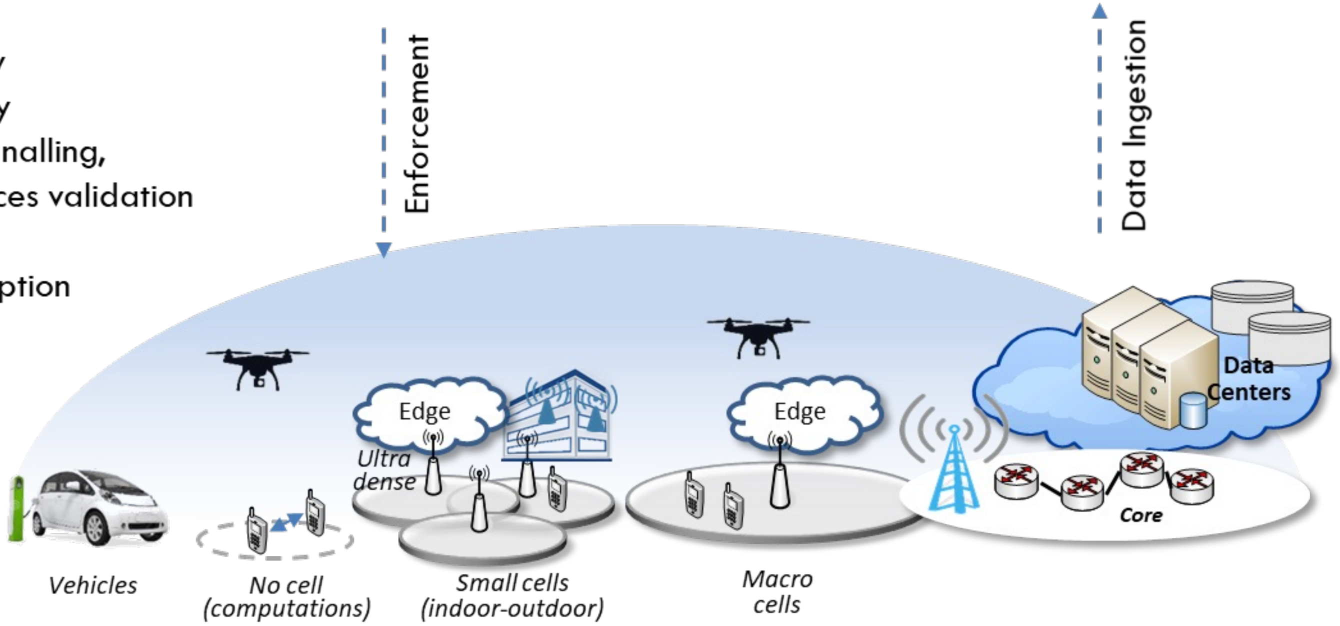
- Decisions (negotiation if time)
- Should an extension of the infrastructure be established?
- Which nodes should be involved? Which spectrum?
- Which edge node will be the termination?
- When to decommission

Awareness

- Trigger,
  - Application with low latency or special security requirements
- Status of candidate infrastructure

Benefits

- Latency
- Security
- Low signalling, interfaces validation
- Energy consumption in infra



Implementation (WINGS infra)

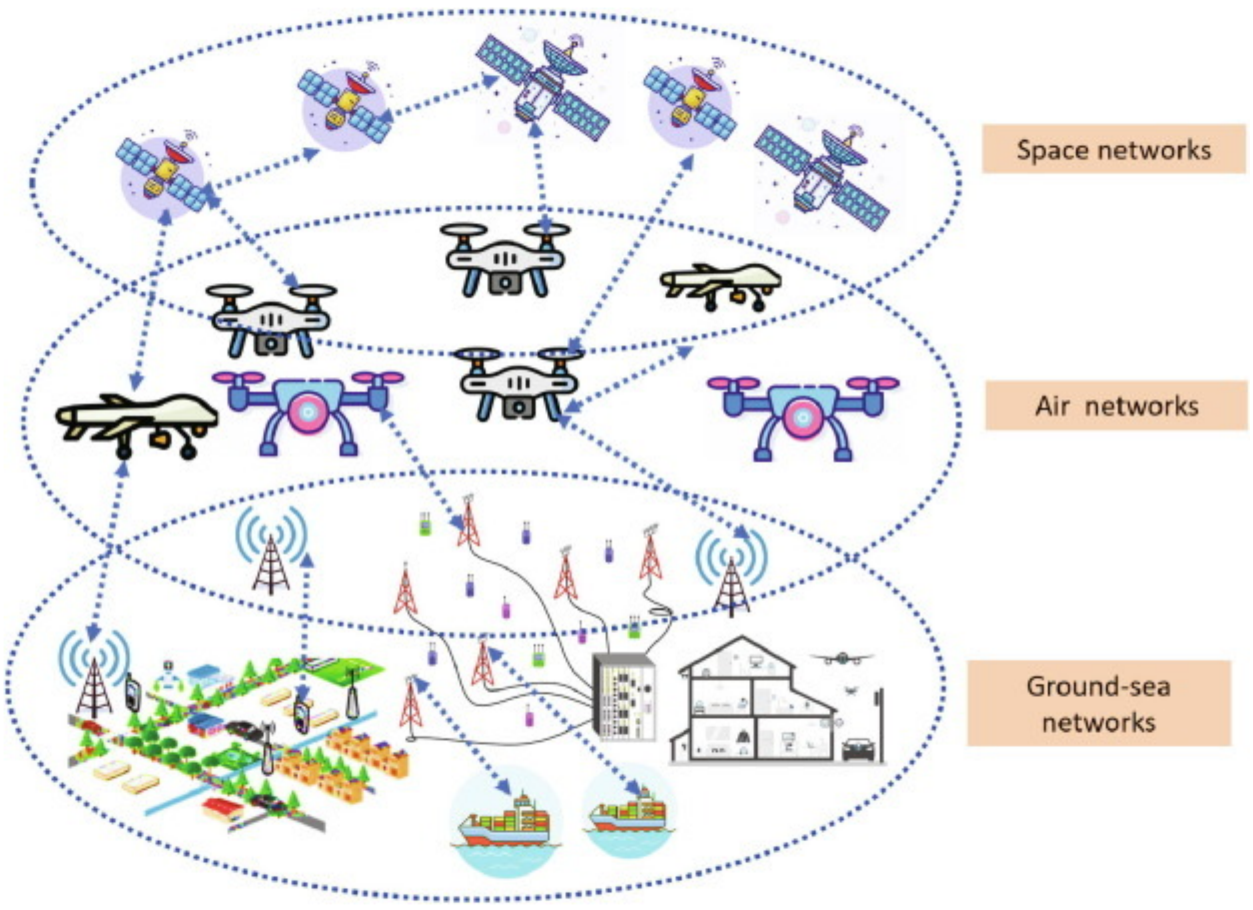
- End devices with various networking capabilities
- USRPs as BSs (and end user transmitters)
- MiniPCs as edge servers
- Infrastructure elements
- Extended with other partners

Functions

- Task 4.3 (open to 4.x)
- Open to partners
- Potential to interact with WP3/Task 3.3 (complement approaches), and WP6 (mechanisms for orchestration for enforcement)

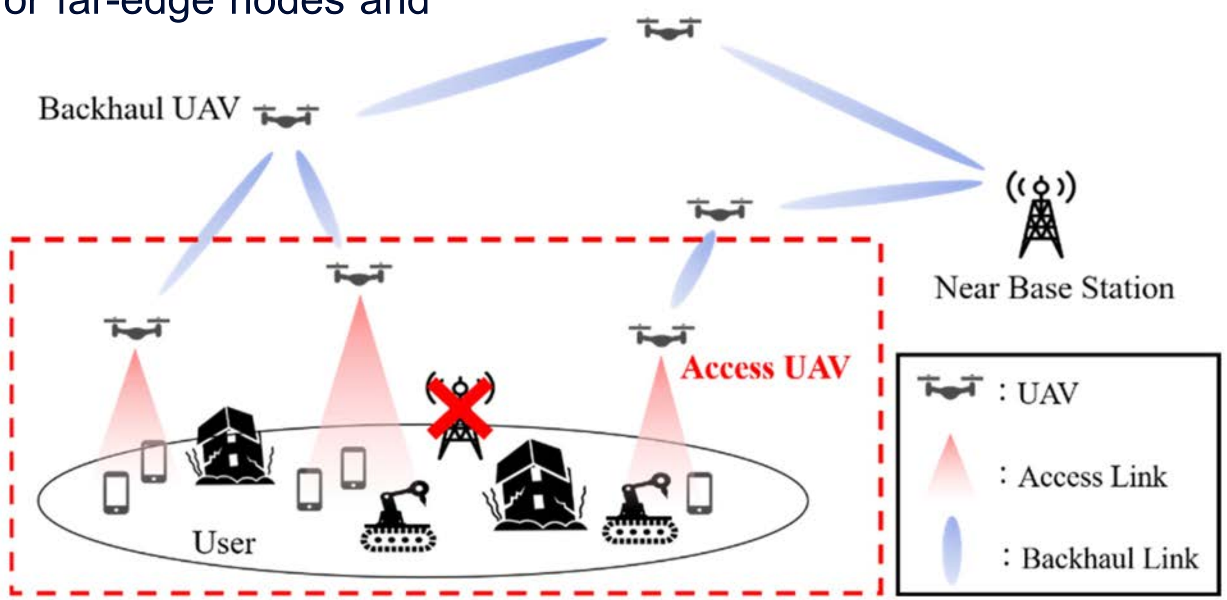
6G Aspects and FLEX-TOP as an Enabler

- **Network Architectures & Technologies**: 6G will focus on improved communication between humans and machines, seamless integration of various network types, and the deployment of new communication interfaces in the new so-called network of networks.
- **Device Trends**: Devices will evolve to include smart wearables, integrated headsets, and implants, leading to the potential end of traditional smartphones.
- **Network Flexibility**: Modularization, open interfaces, and software-defined networking will enable customizable, adaptable, and interoperable network solutions.
- **AI & ML Trends**: Integration of AI and ML will enhance network performance, optimize operations, and ensure more efficient resource management.
- **Cell-less Architecture**: UEs will connect to multiple access points simultaneously, providing improved connectivity and reduced handover latency.
- **Non-Public Networks** (NPNs): NPNs will allow for customized, end-to-end service management and mobility for devices without dual SIM connectivity.
- **FLEX-TOP**: A key enabler for integrating these aspects, providing a versatile and dynamic network infrastructure that can adapt to various requirements and scenarios.



Flexible Networks & Challenges in 6G

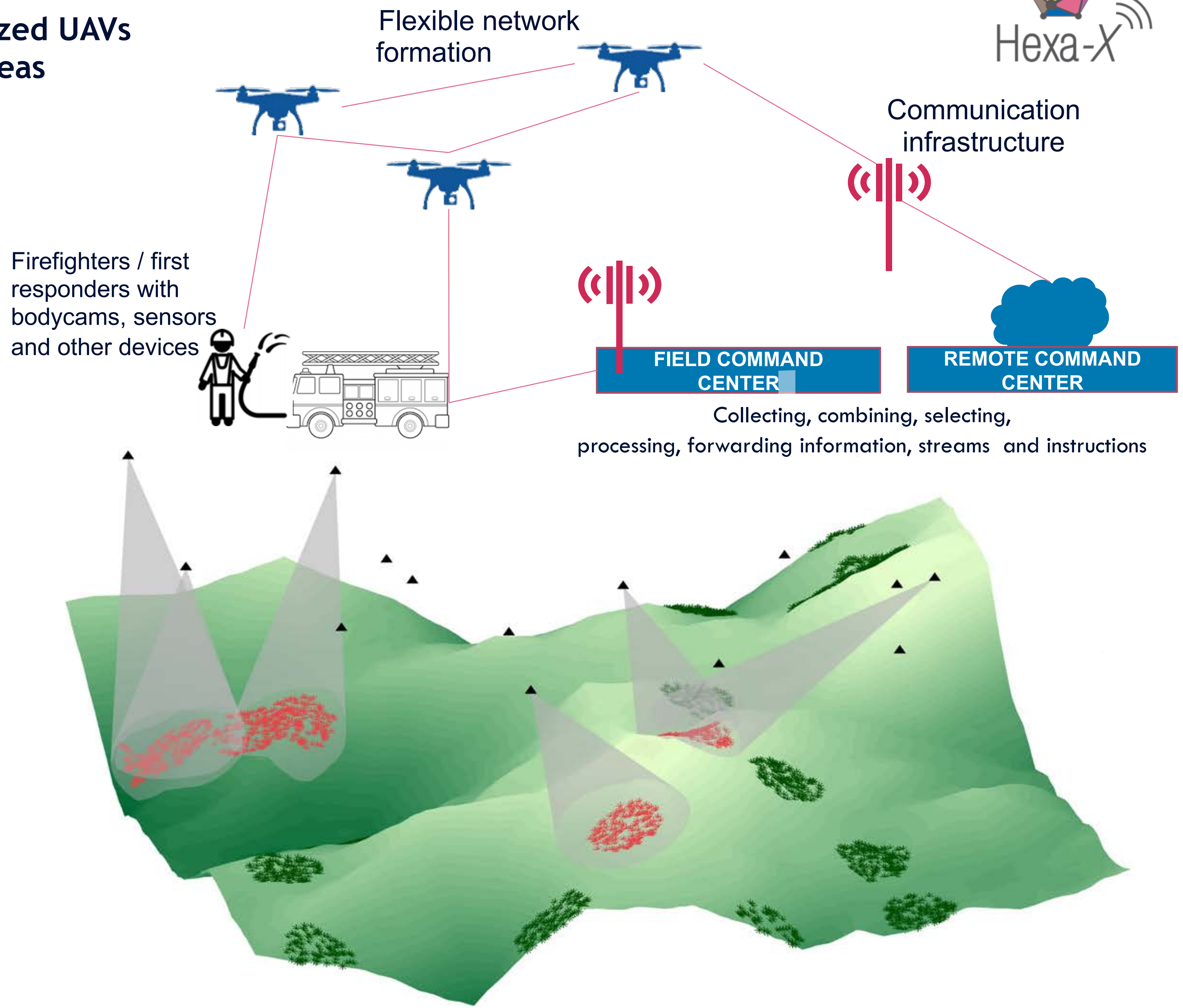
- **Flexibility to Different Topologies:** Adapts to new private networks, autonomous networks, mesh networks, and new spectrum.
- **Scalability:** Supports small to large-scale deployments and dynamic scalability of network resources.
- **Resilience and Availability:** Utilizes multi-connectivity and separation of CP and UP, ensuring local network survivability.
- **Network of Networks:** Integrates Non-Terrestrial Networks, Flexible Multi-connectivity, Sub-THz nodes, L1/2-mobility, Flexible D2D, and Campus/non-public networks.
- **Local Controller:** Manages ad-hoc networks, topology changes, and resource distribution.
- **Information Modeling:** Enables a unified modeling approach for far-edge nodes and devices, supporting distributed intelligence.
- **Challenges in D2D and Mesh Networking:**
  - Trustworthiness of devices.
  - Unified modeling of far-edge nodes and devices.
  - Interface definition for control and interaction.
  - Node selection algorithms.
  - Orchestration integration for seamless management.
  - Node and device discovery methods.
  - Optimized routing for multi-hop D2D communications.
  - Selection of technologies for D2D communications.



FLEX-TOP Framework

Evaluating the Feasibility of Using Specialized UAVs for Wildfire Monitoring in Remote Rural Areas

- Background: Challenges in wildfire monitoring and response in remote rural areas
- FLEX-TOP enabler solution: A novel approach to address connectivity and computing requirements
- Scenario: Firefighters equipped with sensors (thermal/hyperspectral cameras, temperature sensors, etc.)
- Aim: Assess the feasibility and effectiveness of using specialized UAVs vs. pre-deployed static infrastructure for streaming multimedia footage
- Flexible Topologies Framework: Balancing infrastructure costs, energy consumption, trustworthiness, and sustainability



Problem Formulation

Optimal Traffic Source - AP (UAV) Association Matrix and UAV Deployment

- Problem: I TSs need to be served by J APs in a rural area, subject to certain constraints and assumptions.
- Assumptions: Each AP j has an initial trust index T_j, cost of deployment K_j, capacity Cap_j, and energy capacity $CapE_j$, while each TS i has a load and energy consumption L_i, E_i.
- Notations: Y is a binary vector denoting which APs are used and X is a binary matrix denoting which TS-AP links are active, respectively. C is the connection cost matrix with C_{ji} denoting the cost of the link $TS_i - AP_j$.
- Objective: Find association matrix X based on which the trust is maximized, and the cost is minimized.
- Constraints: Each TS must be connected to at most one AP, and the load and energy consumption of active links for each AP should be less than or equal to its capacity and energy capacity, respectively.
- Linear programming techniques can be applied to solve this optimization problem.

$$\text{Object:} \quad \max_{X} \left[\sum_{j=1}^{J} [T_j - K_j] Y_j - \sum_{j=1}^{J} \sum_{i=1}^{I} X_{ji} C_{ji} \right]$$

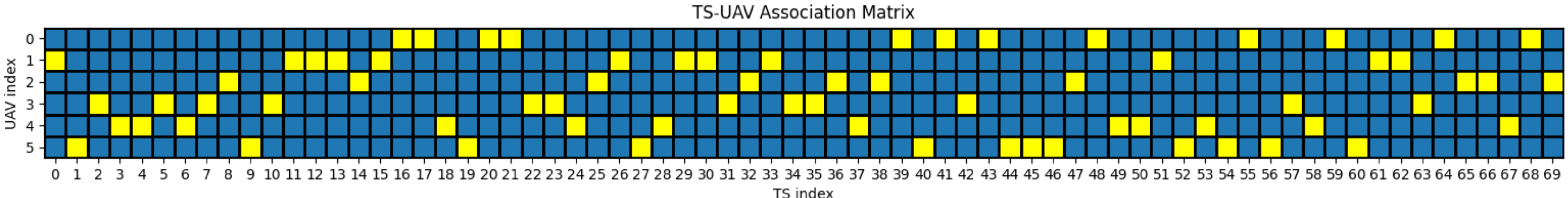
$$\text{s.t.} \quad \sum_{j=1}^{J} X_{ji} = 1$$

$$\sum_{i=1}^{I} X_{ji} L_i \leq Cap_j Y_j$$

$$\sum_{i=1}^{I} X_{ji} E_i \leq CapE_j Y_j$$

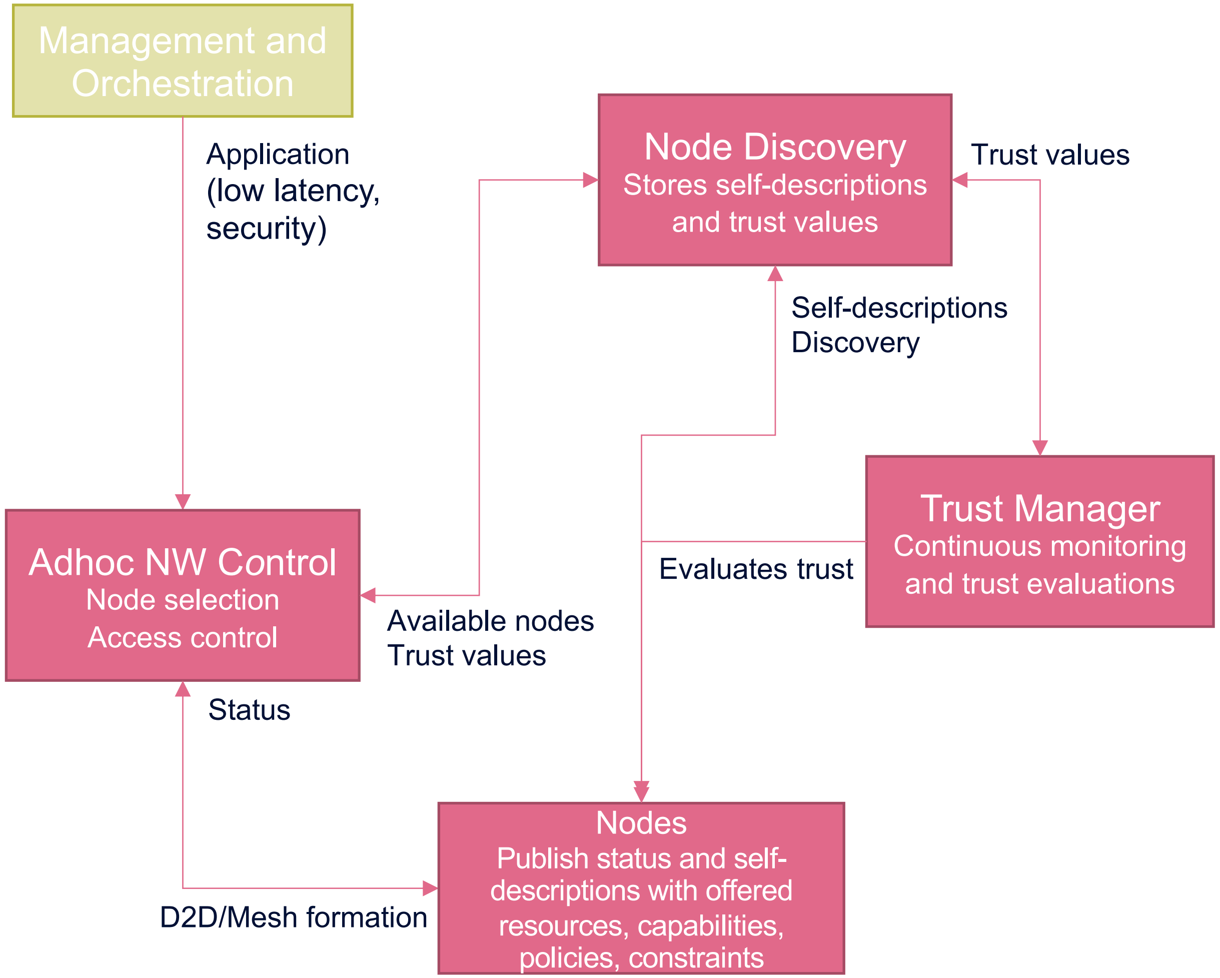
$$\mathbf{Y} \in \{0,1\}^{Jx1}, \ \mathbf{X} \in \{0,1\}^{JxI}, \ \mathbf{C} \in R_{\geq 0}^{JxI}$$

$$\mathbf{T}, \mathbf{K}, \mathbf{Cap}, \mathbf{CapE} \in R_{\geq 0}^{1xJ}, \ \mathbf{L}, \mathbf{E} \in R_{\geq 0}^{1xI}$$



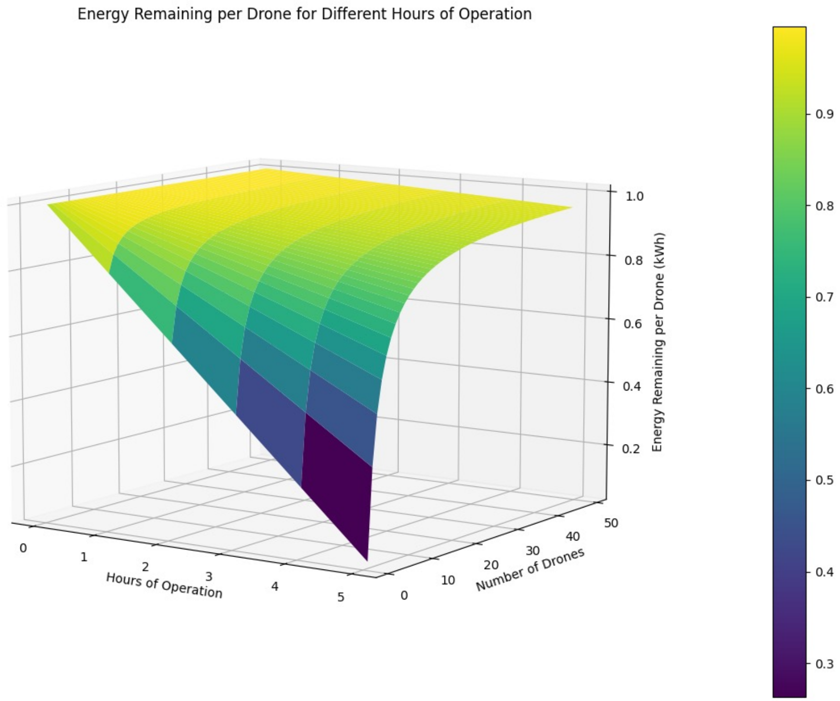
Algorithmic Insight

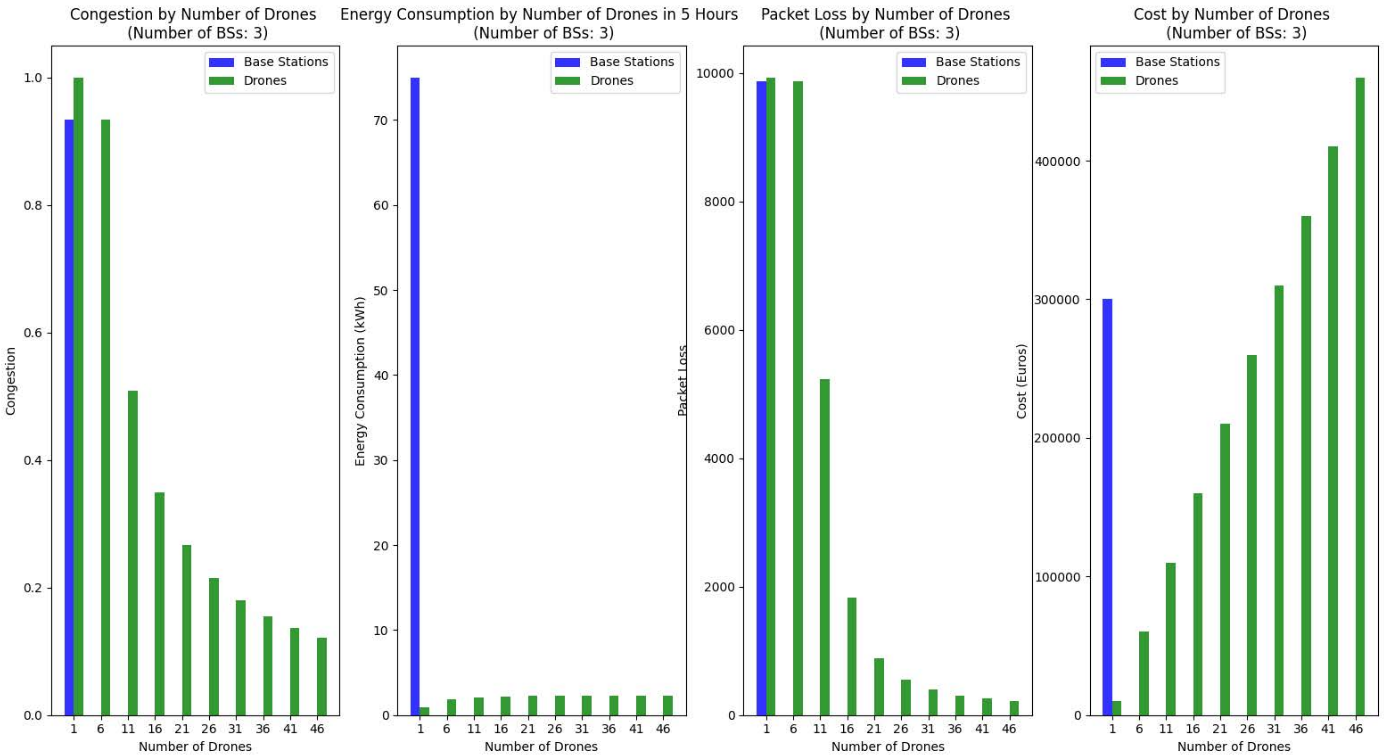
- Initialize variables: No of users, user rate, BS/UAV capacity, costs, etc.
- Find the number of APs needed and calculate KPIs for both static infrastructure and flexible access nodes [input: current infrastructure, # TSs, output: # APs, node congestion, energy consumption]
- Find Association Matrix X and provide KPIs [input: # TSs, # APs, AP (trust, cost, capacity, energy), TS: (load, energy), K (deployment cost), C (cost matrix), output: Association Matrix X, inclusion]
- Simulate ecosystem and calculate KPIs [input: # TSs, # APs, costs, TSs capacity, sensor rate, PER, packet sizes, etc., output: utilization of nodes, efficiency of resource allocation, mean user info rate, mean user packet loss]



Flexible vs static infrastructure comparative analysis

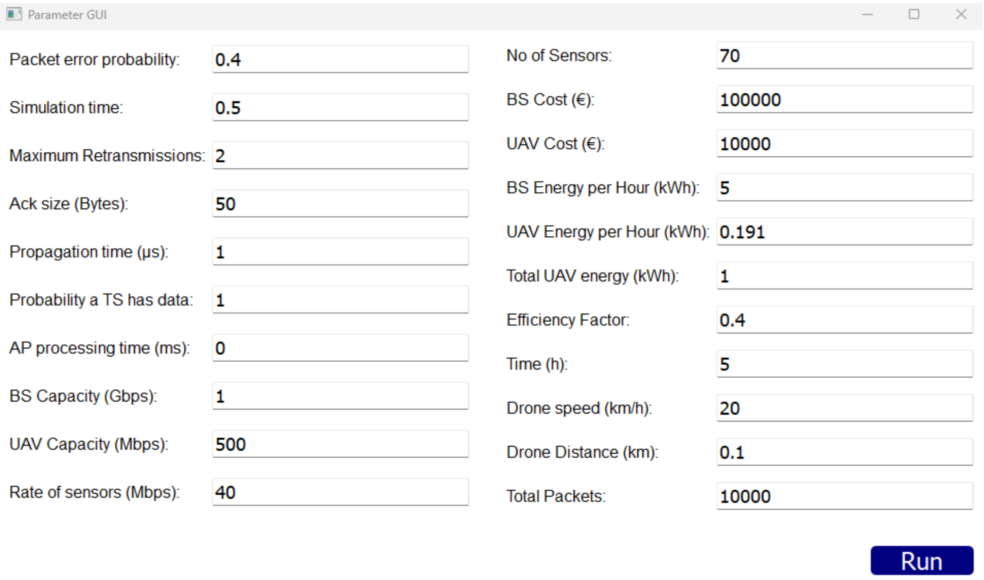
- Evaluating the impact of different UAV numbers on different KPIs (node congestion, energy consumption, packet loss)
- Cost-effectiveness of using drones vs. static infrastructure
- Plot analysis: Impact of the number of UAVs deployed and operation duration on energy remaining per UAV

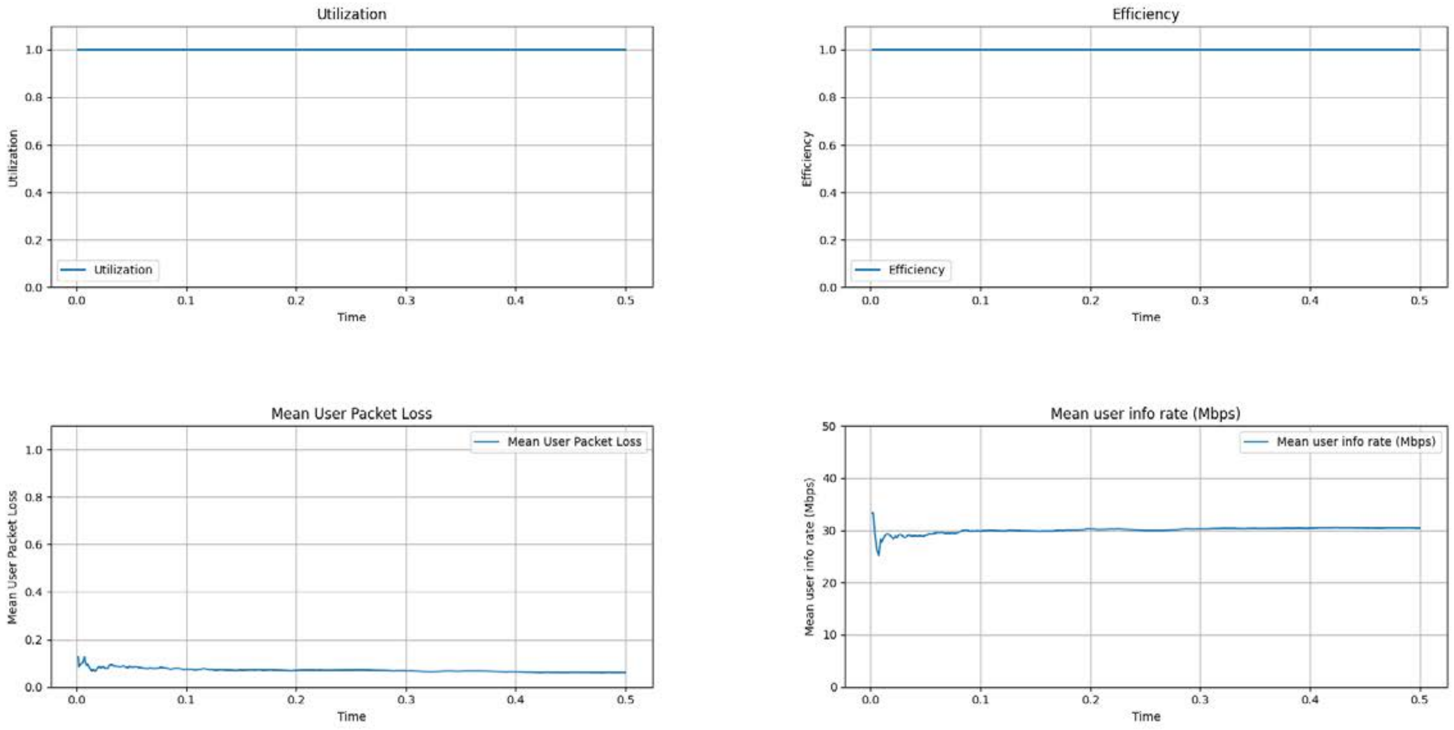




Simulation Design and Results

- Python-based simulation model replicating rural area conditions
- Key parameters: existing infrastructure / UAV characteristics, user demands
- Ecosystem simulation and KPIs calculation
- Investigate benefits and drawbacks





Future Directions

- Analyze the results and identify potential improvements in the infrastructure or UAV deployment strategy.
- Investigate the trade-offs between different KPIs and explore alternative configurations to optimize the system.
- Perform sensitivity analysis to understand the impact of variations in input parameters on the system performance.
- Validate the framework with real data and extreme 6G use cases (XR, Massive Twinning).
- Use the insights gained from the simulation to guide decision-making on network planning and resource allocation.

Thank you!

HEXA-X.EU

Hexa-X