

# Lower energy consumption in mobile networks through operator cooperation driven by autonomous digital twins

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# Antennas and Transceivers

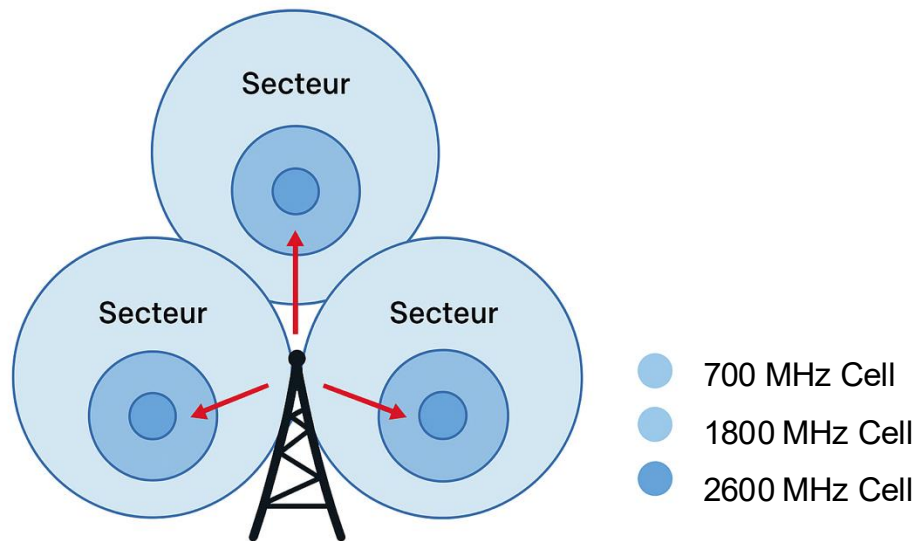


Figure 1: Cellular structure of the RAN

- A base station consists of at least one or several antennas
- An antenna has one or several transceivers
- Sector: coverage area of a transceiver
- A transceiver operates on a frequency band of a specific radio technology (LTE 2600)
- Physical Resource Block (PRB) Load: indicates the network utilization rate at a given moment

# RAN and Energy Consumption

« According to the French association The Shift Project, **digital technologies** accounted for **3.7%** of **global greenhouse gas emissions** in **2018** (compared with 2.5% in 2013). This is higher than air traffic. Moreover, the energy footprint of digital technology is growing by 9% per year. » [1]

This consumption depends [2]:

- On equipment needed to keep the station active, particularly transceivers
- Very little on traffic => 90% of its maximum power, even when traffic demand is low or almost non-existent

[1] [https://fr.wikipedia.org/wiki/Efficacit%C3%A9\\_%C3%A9nerg%C3%A9tique\\_des\\_communications\\_5G](https://fr.wikipedia.org/wiki/Efficacit%C3%A9_%C3%A9nerg%C3%A9tique_des_communications_5G)

[2] F. S. Han. "Energy-Efficient Base-Station Cooperative Operation with Guaranteed QoS". In: IEEE Transactions on Communications (2013).

# Problem Statement

How to reduce energy consumption and carbon footprint of base stations?

# State of the Art

Intra-operator case [2]:

- Temporary **Base Station (BS) shutdown + Coverage extension** from neighboring BSs
- Result: energy savings + QoS maintenance

## Limitation

Theoretical models or global assumptions regarding traffic and network topology

Inter-operator case [3,4]:

- Alternating shutdown of a complete network or part of a network (certain BSs) + traffic offloading to other operators

Strong hypothesis:

- on base station location
- on base station coverage

[2] F. S. Han. "Energy-Efficient Base-Station Cooperative Operation with Guaranteed QoS". In: IEEE Transactions on Communications (2013).

[3] M. Ajmone Marsan. "Energy efficient management of two cellular access networks". In: ACM SIGMETRICS Performance Evaluation Review (2010).

[4] A. K. Bousia. "Game Theoretic Approach for Switching Off Base Stations in Multi-Operator Environments". In: IEEE ICC (2013).

# Approach

**Proposed Solution:** Turn off **underutilized transceivers** and, after negotiating, transfer the residual traffic to transceivers of **other operators** installed on the same site, using **autonomous digital twins (ADT)** [5].

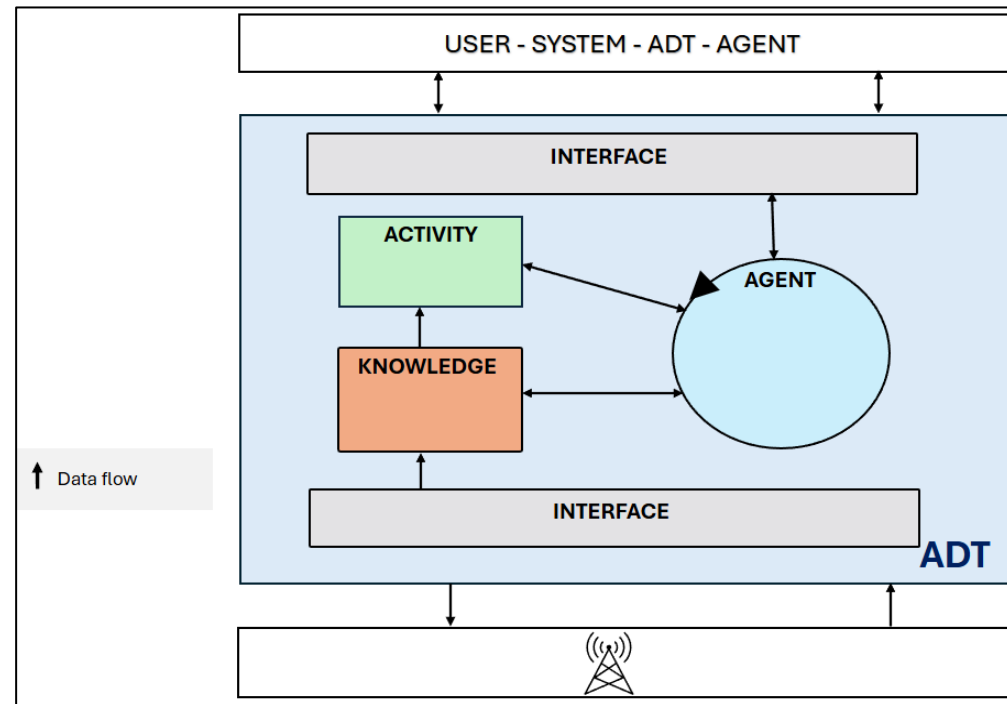
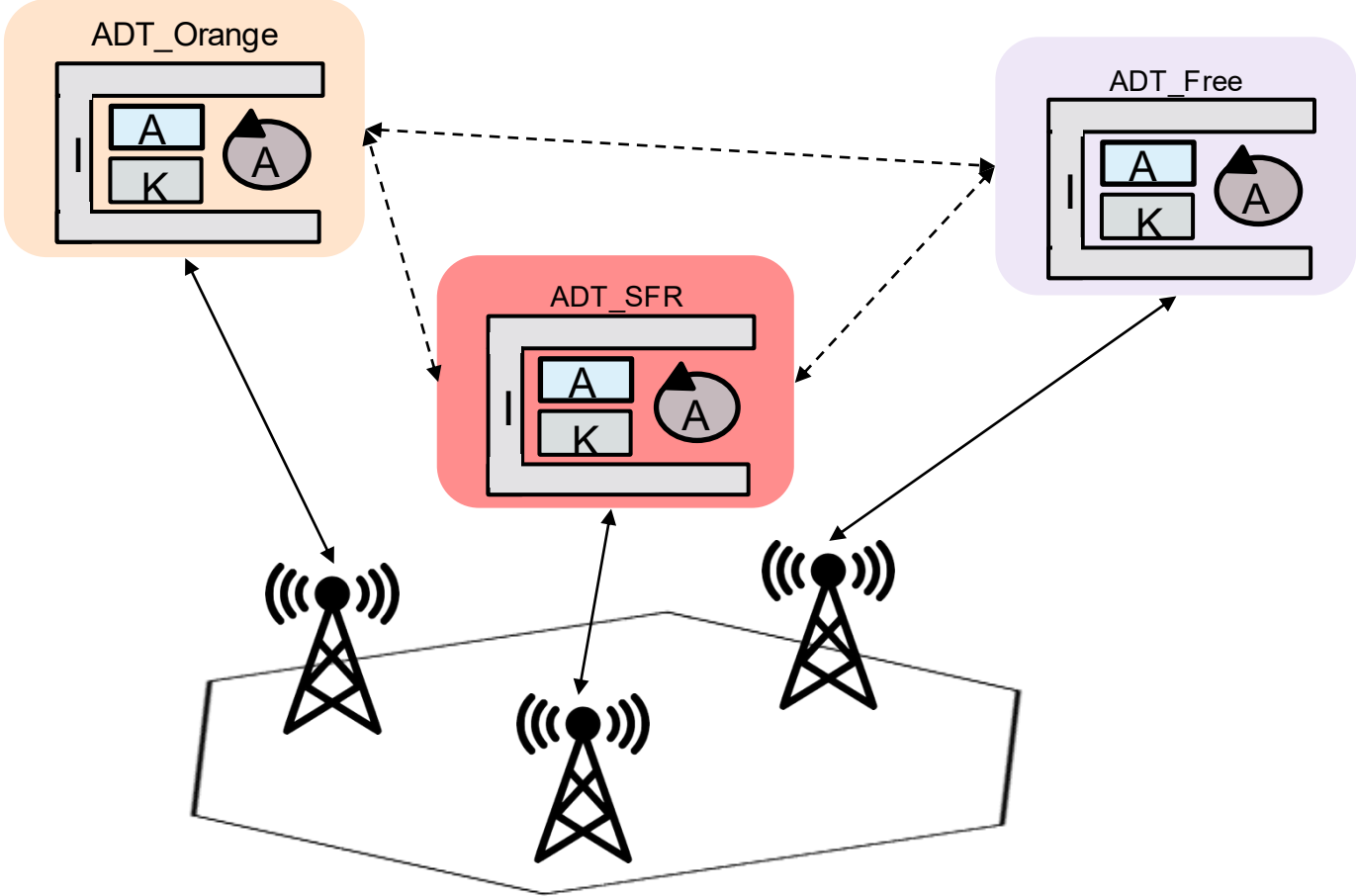


Figure 2: Overall architecture of an ADT [5]

[5] MUCHIKA, Miriam Zawadi. Autonomous Digital Twins: a new architecture for decision-making in Open Cyber-Physical systems. In : Doctoral Consortium at the 27th European Conference on Artificial Intelligence (DC-ECAI 2024). 2024.

# ADT Deployment Schema



←→ Synchronized/ACT  
←- - - -> Collaborate

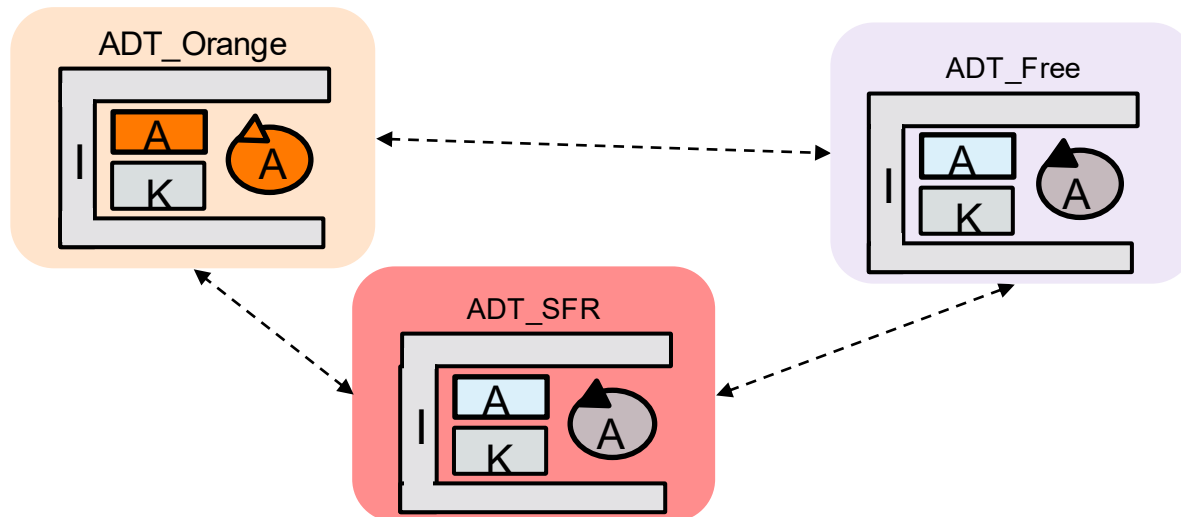
Figure 3: ADT deployment Schema [5]

[5] MUCHIKA, Miriam Zawadi. Autonomous Digital Twins: a new architecture for decision-making in Open Cyber-Physical systems. In : Doctoral Consortium at the 27th European Conference on Artificial Intelligence (DC-ECAI 2024). 2024.

# Process Flow

1. Identification of underutilized transceiver
2. Request for negotiations with other operators' base stations on the same site
3. Transceiver selection
4. Receiving candidate transceiver and selecting the host transceiver
5. Switching off the initiator transceiver

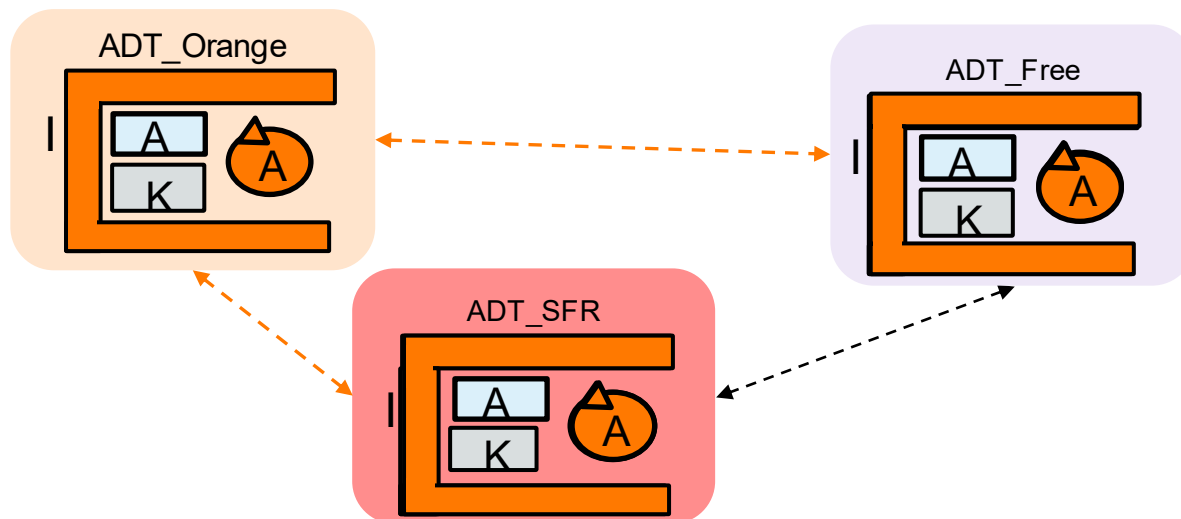
- Analysis of transceiver states
- Identifies those with PRB load below a threshold set by the operator (e.g., 10%)
- These transceivers are considered underutilized



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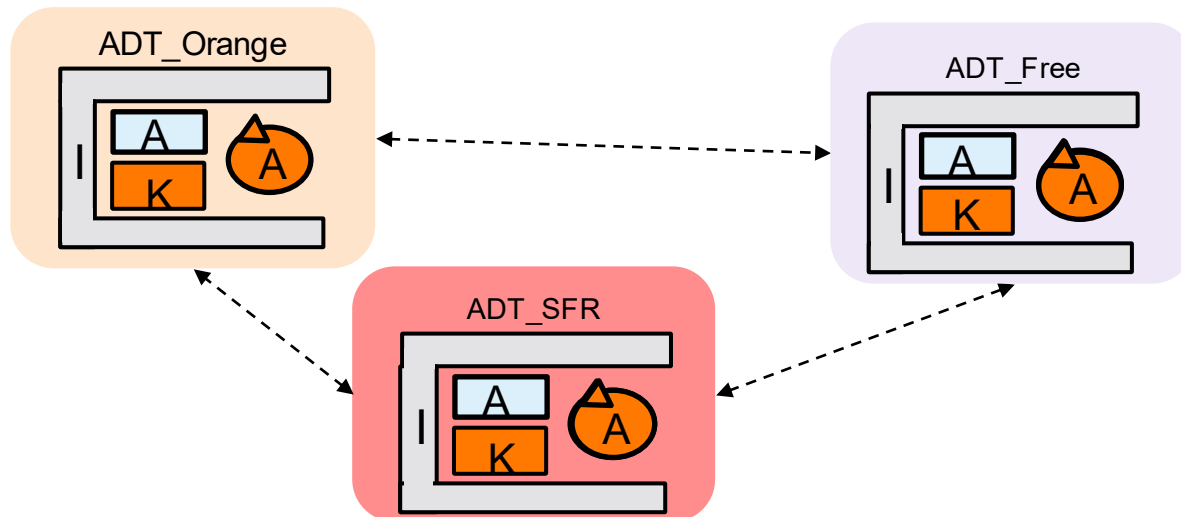
- For each underutilized transceiver, a message is sent to all other ADTs on the same site
- **Message content:**
  - Underutilized transceiver identifier
  - Frequency band
  - Azimuth
  - Load to transfer in PRB
- **Objective:** Ask who can handle this traffic?



# Process Flow

1. Identification of underutilized transceiver
2. Request for negotiations with other operators' base stations on the same site
3. **Transceiver selection**
4. Receiving candidate transceiver and selecting the host transceiver
5. Extinguishing the initiator transceiver

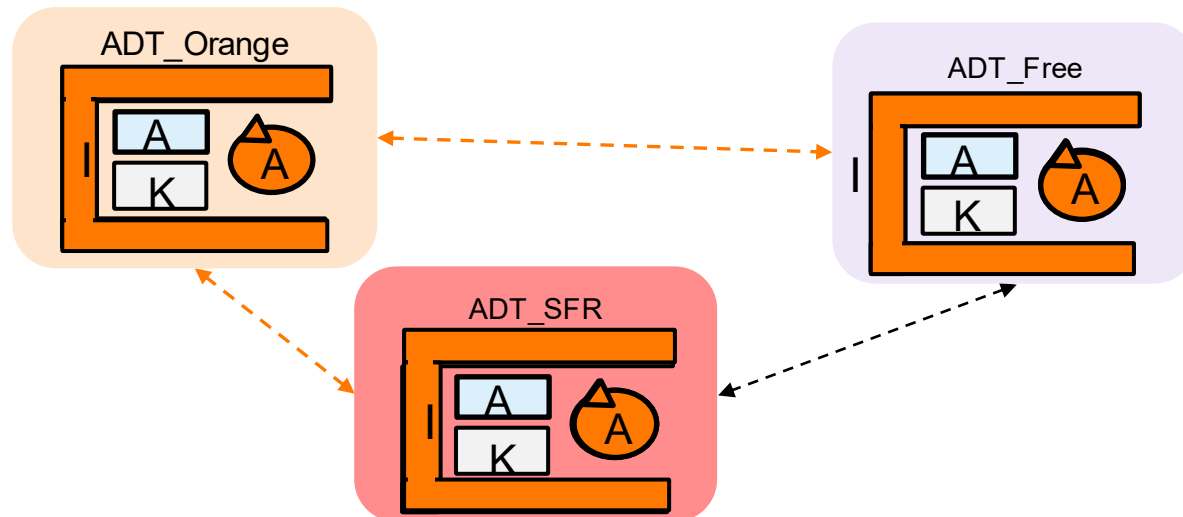
- Each contacted **ADT** analyzes its own network (Knowledge Graph)
- Identifies transceivers capable of hosting residual traffic according to compatibility criteria:
  - Close azimuth (defined tolerance margin)
  - Sufficient coverage angle
  - Lower or equal frequency band
  - Available absolute PRB
- **Result:** A candidate list is generated



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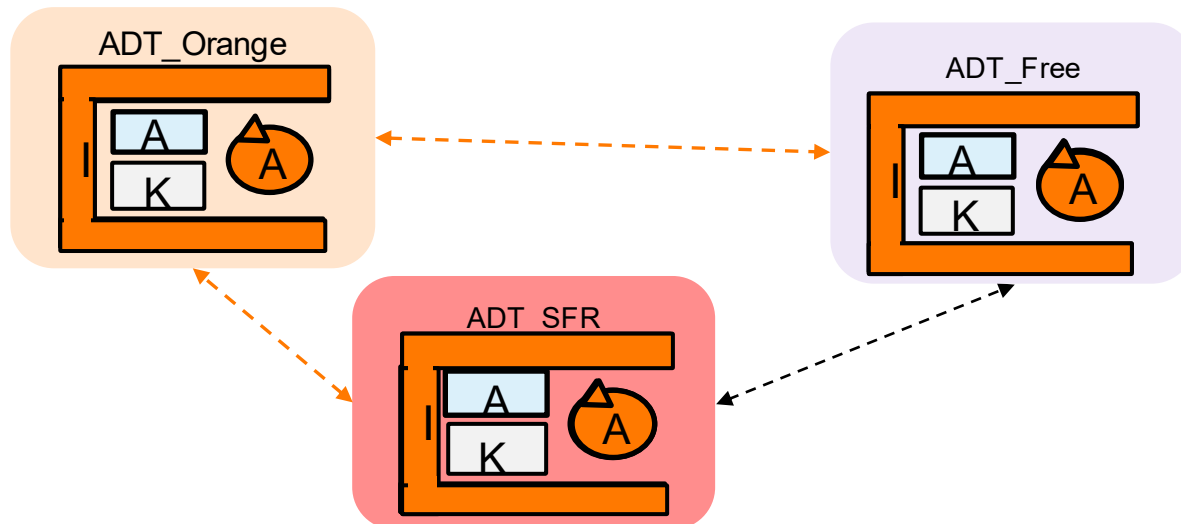
- Each ADT sends its candidate transceiver list to the initiating operator
- Candidate comparison according to several criteria:
  - PRB availability (avoid overload)
  - Frequency band (lower = better coverage)
  - **Cost function:**
    - Carbon footprint minimization
    - Energy savings balance between operators
- Decision making based on computational argumentation algorithm [6]



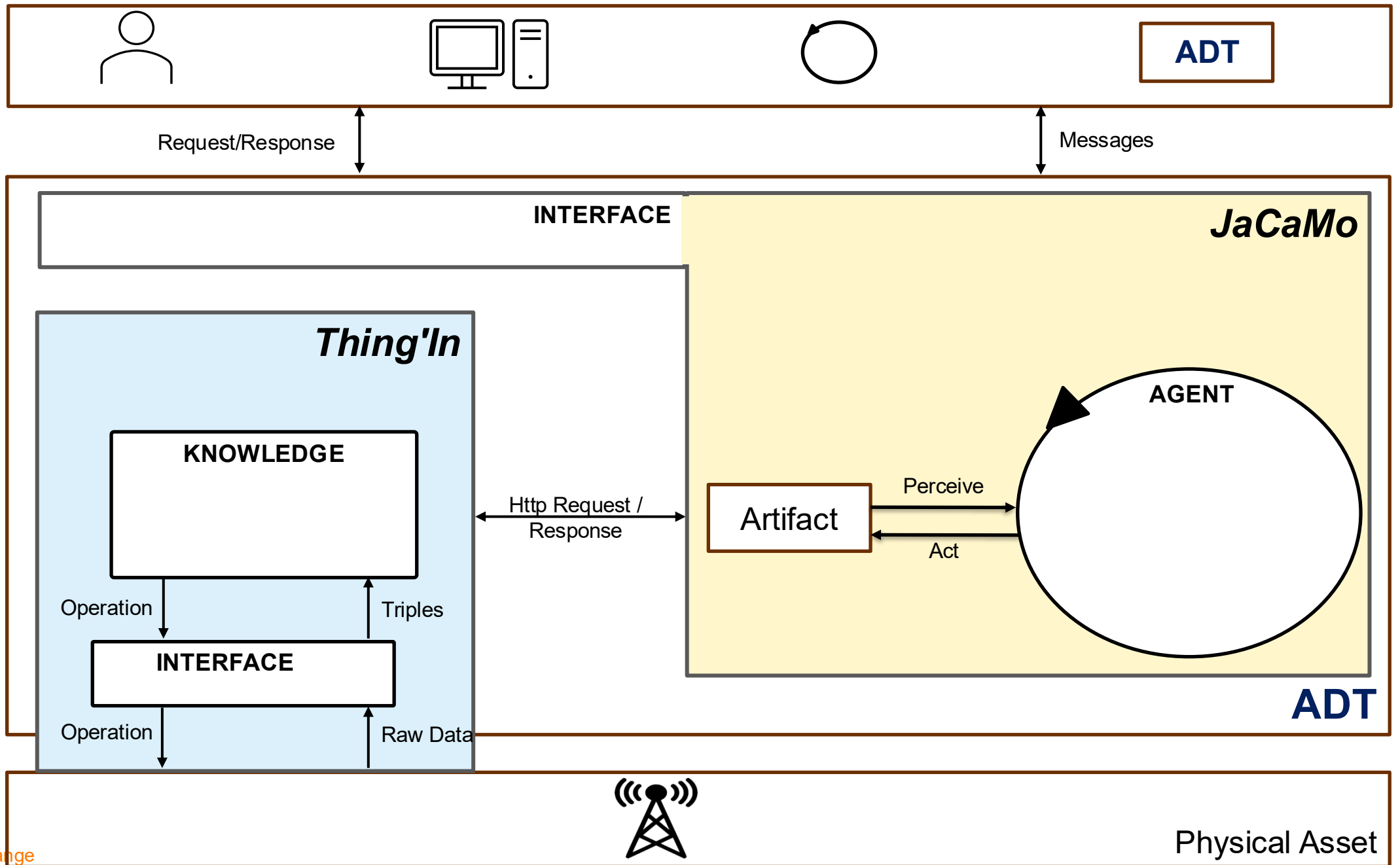
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- Decision announcement to participating ADTs
- Confirmation from ADT whose transceiver is selected as host and traffic handling
- Shutdown of underutilized transceiver



# Experimentations



# Dataset

**Data Source:** Orange Information System **Observation**

**Period:** From 21/05/2025 at 00:00 to 21/05/2025 at 23:00

**Information:** Hourly PRB load measurements

**Content:**

- PRB Load (%) per cell
- Geographic coordinates (longitude, latitude) and location information
- **Technology studied:** 4G only
  - Present throughout the territory
  - More recent than 2G/3G
  - More widespread than 5G

# Firminy Site




Informations disponibles ✕

**SITE 446335**

**Détail du site :**

N° identification : 446335  
Description du site : Pylône autostable / 38m / TDF  
Adresse : R BERTHELOT LE CRASSIER  
Code Postal / Commune : 42700 FIRMINY  
Coordonnées : 45.39889, 4.2875

**Téléphonie**

 <a href="#">2G/3G/4G/5G</a>	 <a href="#">2G/3G/4G/5G</a>
 <a href="#">3G/4G/5G</a>	

**TNT**

Imprimer / Télécharger Fermer ✕

Figure 4: Cartoradio details on the Firminy site

# Simulation of Data for Other Operators

**Problem:** Data available only for Orange's BS

**Solution:** Simulation of loads for other operators (SFR-majority, Free)

**Hypothesis:**

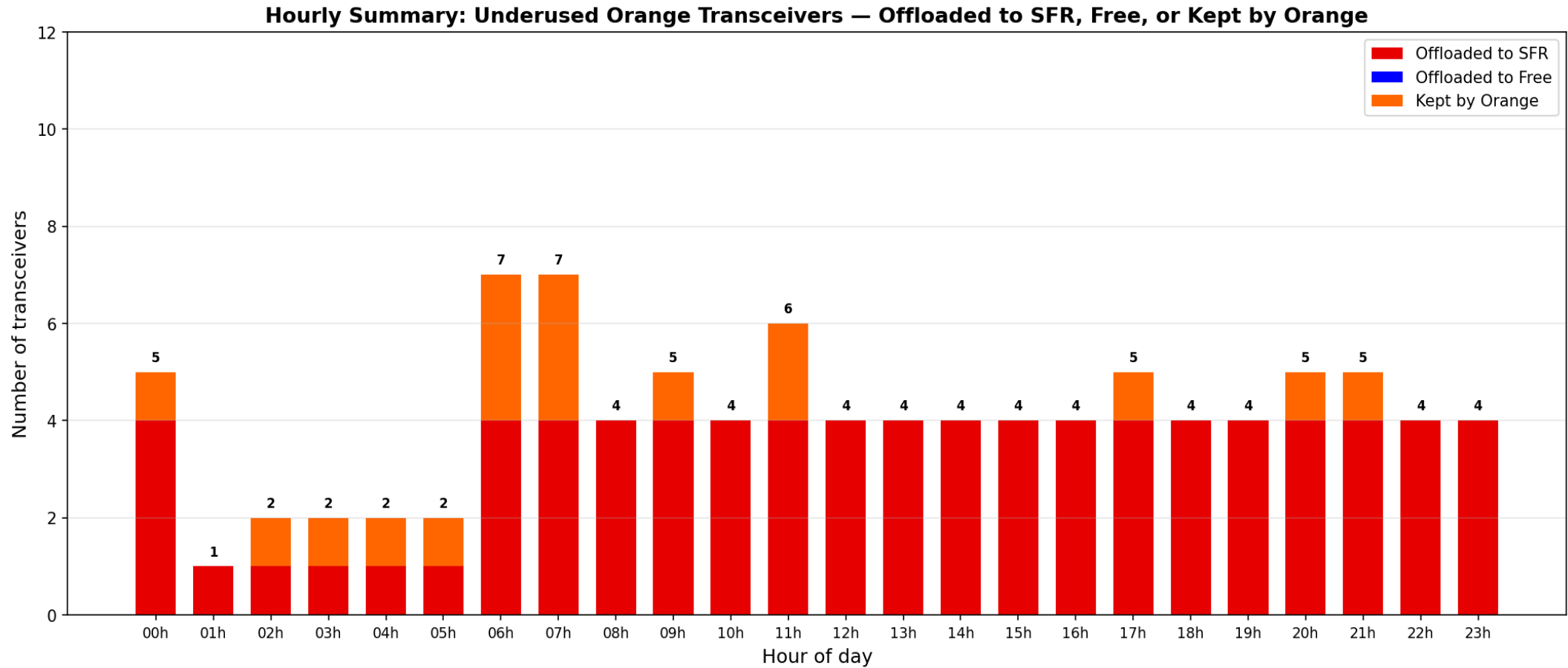
- Distribution follows local market shares

**Method:**

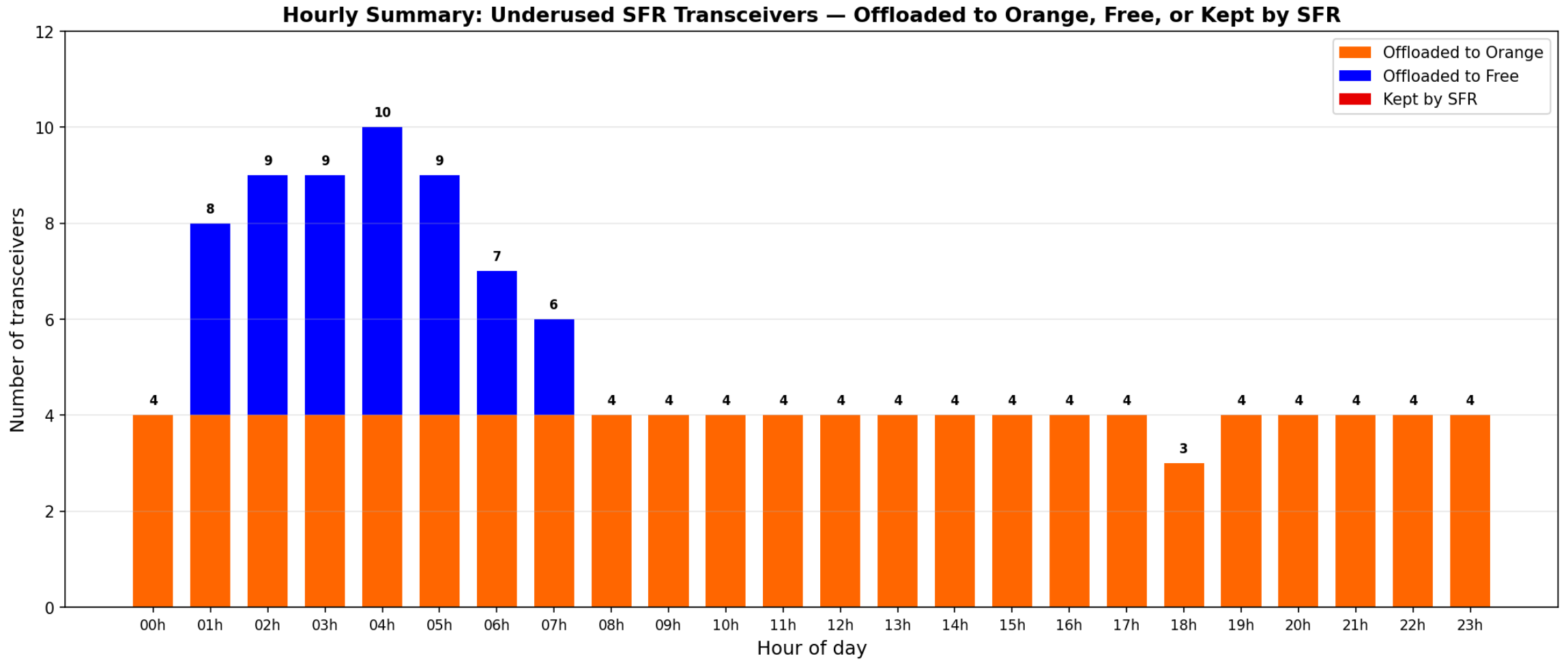
- Estimate total load:  $\text{TotalLoad} = \text{Orange load} / \text{Orange share}$
- Deduce simulated load for each operator:  $\text{simulated load} = \text{operator share} \times \text{TotalLoad}$

**Advantage:** Temporal consistency with real data + respect for competitive structure

# Orange wants to switch off his underused transceiver



# Sfr wants to switch off his underused transceiver



# Conclusion and Perspectives

## Achievements:

- Active infrastructure sharing between operators (transceiver)
- Approach implemented with Autonomous Digital Twins (ADT) capable of making decisions
- Patent application

## Perspectives:

- Calculate carbon footprint gain
- Scale-up

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# Thank you