Digital Twin Networks and Secure and Autonomous Orchestration of Beyond 5G Systems through Intent-Aware and Value-Driven Optimization

Federica de Trizio, PhD student

Research Area Telecommunication Networks
Supervisors Profs. Giuseppe Piro, Gennaro Boggia

Freepik vectors

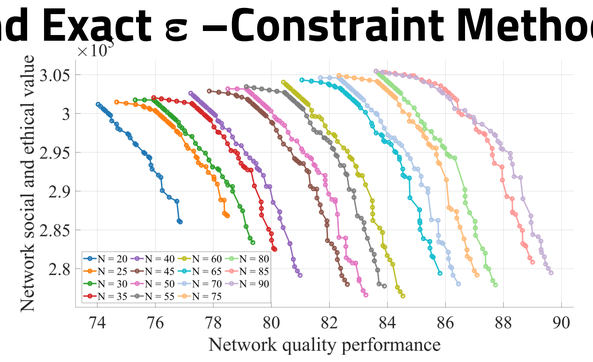
The evolution of 5G has increased the **complexity of telecom infrastructures**, challenging traditional network management focused solely on KPIs – but high performance does not necessarily translate to a positive user experience or benefit.

In line with the UN SDGs, networks must address broader **ethical and social values**. Current approaches overlook the need for a multi-faceted approach and multi-objective optimization, inherently complex, as it involves navigating trade-offs between conflicting goals.

Digital twins emerge as solutions enabling accurate simulation and predictive maintenance. Coupled with **Intent-Based Networking**, which translates high-level objectives into network actions, digital twins can support decision-making processes that align both performance and societal values.

Multi-Objective Optimization and Exact ε –Constraint Method

- **Exact multi-objective optimization:** the ε-constraint method enables the identification of all Pareto-optimal trade-offs, offering decision-makers greater transparency and control compared to heuristic or weighted-sum strategies.



$$\max_X (Q(X), V(X)),$$
$$\text{s.t.} \quad \left(Q_{r_n,s_j} - Q_{tol_{s_j}}\right) \cdot x_{r_n,s_j} \geq 0, \forall s_j \in \mathcal{S}, \forall r_n \in \mathcal{R},$$
$$V_{r_n,s_j} \cdot x_{r_n,s_j} \geq 0, \forall s_j \in \mathcal{S}, \forall r_n \in \mathcal{R},$$
$$\sum_{s_j \in \mathcal{S}} D_{s_j} \cdot x_{r_n,s_j} \leq A_{r_n}, \forall r_n \in \mathcal{R},$$
$$\sum_{r_n \in \mathcal{R}} x_{r_n,s_j} = 1, \forall s_j \in \mathcal{S}$$
$$x_{r_n,s_j} \in \{0,1\}, \forall s_j \in \mathcal{S}, \forall r_n \in \mathcal{R}$$

$$\max_X V(X)$$
$$\text{s.t.} \quad Q(X) \geq \varepsilon,$$
$$\left(Q_{r_n,s_j} - Q_{tol_{s_j}}\right) \cdot x_{r_n,s_j} \geq 0, \forall s_j \in \mathcal{S}, \forall r_n \in \mathcal{R},$$
$$V_{r_n,s_j} \cdot x_{r_n,s_j} \geq 0, \forall s_j \in \mathcal{S}, \forall r_n \in \mathcal{R},$$
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$$x_{r_n,s_j} \in \{0,1\}, \forall s_j \in \mathcal{S}, \forall r_n \in \mathcal{R}$$

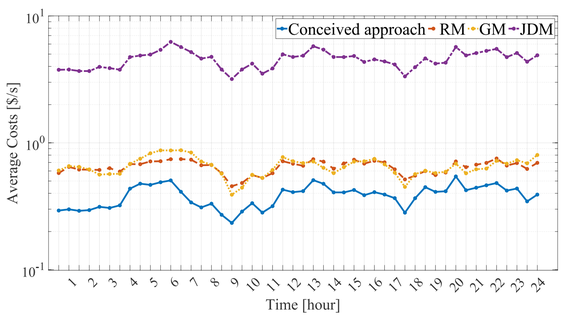
G. Sciddurlo, **F. de Trizio**, G. Piro, G. Boggia, *A Value-Driven System Design Framework for Sustainable 6G Networks*, Computer Networks (Elsevier), 2025, vol. 269, pp. 111477

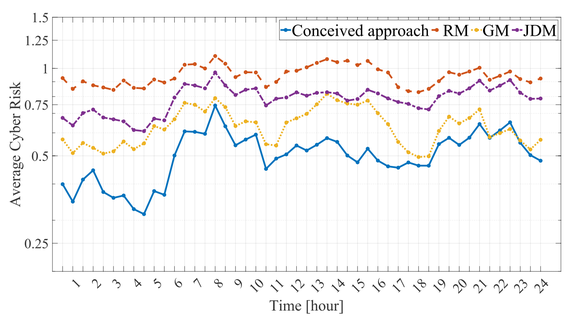
F. de Trizio, M. Marchese, G. Sciddurlo, G. Piro, G. Boggia, *GreenTent: an Intent-based Framework for Sustainable Network Orchestration*, submitted to the 2025 IEEE Conference on Network Function Virtualization and Software Defined Networks (NFV-SDN) (NFV-SDN'25)

Game Theory and Multi-Criteria Decision Making

- **Goal**: associating intents to domains to process them in a timely, efficient, convenient, and safe manner. Achieved through a many-to-many matching game, based on the Gale-Shapley algorithm.
- **Players**: network domains and service requests mapped to categories of intents, derived from B5G service classes.
- **Preferences**: computed with the TOPSIS multi-criteria decision-making algorithm.

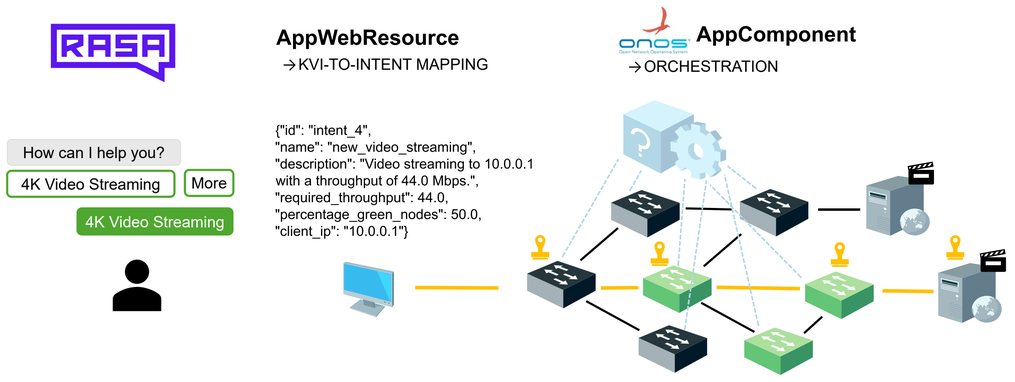
$$\min_{x_{(T_k(R_s^{(n)}),D_m)}} |\mathcal{F}| + |\mathcal{E}| + |\mathcal{C}| + |\mathcal{S}|$$
$$\text{s.t.} \quad \sum_{n=1}^{N} \sum_{s=1}^{S} \sum_{k=1}^{K} x_{(T_k(R_s^{(n)}),D_m)} \leq q^{(m)}, \forall m \in [1,M]$$
$$\sum_{m=1}^{M} \sum_{k=1}^{K} x_{(T_k(R_s^{(n)}),D_m)} = K,$$
$$\forall R_s^{(n)} \in \mathbb{R}^{(n)}, \forall n \in [1,N]$$
$$\sum_{m=1}^{M} \sum_{s=1}^{S} \sum_{k=1}^{K} x_{(T_k(R_s^{(n)}),D_m)} \leq \sum_{m=1}^{M} q^{(m)}$$
$$x_{(T_k(R_s^{(n)}),D_m)} \in \{0,1\}.$$





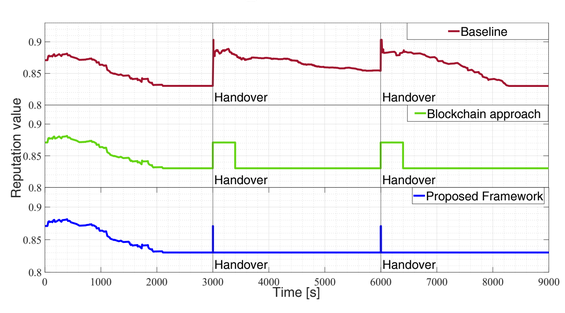
F. de Trizio, G. Sciddurlo, I. Cianci, G. Piro, G. Boggia, *Optimizing Key Value Indicators in Intent-Based Networks through Digital Twins aided service orchestration mechanisms*, Computer Communications (Elsevier), 2024, vol. 228, pp. 107977.

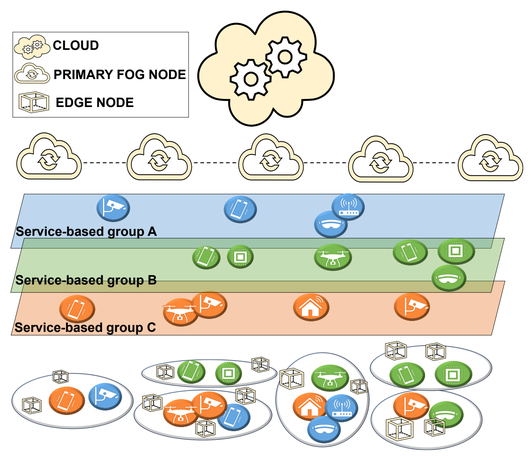
Proof of Concept



… and more value: a Framework for Responsive Trustworthiness Dissemination

- The **Social Internet of Anything (SIoA)** paradigm can improve security and trust, addressing key challenges in IoT such as user visibility and efficient resource and service discovery. Research in this area focused on trust management and evaluation techniques to establish reliable relationships and secure communications, enabling trustworthy information exchange.





F. de Trizio, G. Sciddurlo, A. Petrosino, G. Piro, G. Boggia, *A Scalable Framework for Responsive Trustworthiness Dissemination in Social IoA*, Proceedings of the ACM CoNEXT Student Workshop 2024 (CoNEXT-SW '24), Los Angeles, California, December 2024.

Parallel Scientific Contributions

F. de Trizio, G. Sciddurlo, D. Rutigliano, G. Piro, G. Boggia, *A Novel Malicious Intent Detection Approach in Intent-Based Enterprise Networks*, 20th International Conference on Network and Service Management (CNSM), Prague, Czech Republic, October 2024.

F. de Trizio, G. Sciddurlo, G. Piro, D. Striccoli, I. Cianci, G. Boggia, *Surviving Disaster Events Via Dynamic In-Network Processing Assisted by Network Digital Twin*, in 2023 International Conference on Information and Communication Technologies for Disaster Management (ICT-DM), Cosenza, Italy, Sep. 2023

Awards

COHERENT partners, *Demonstration of a complete Digital Twin Network developed and integrated within the COHERENT project*, **Best Project Contribution winner**: Plenary Dissemination Workshop, Napoli, Italy, 30.06.2025.

G. Sciddurlo, **F. de Trizio**, G. Piro, G. Boggia, *Integrating Digital Twin Federation and Intent-Based Networking for Optimized Performance in Ethical Next-Generation Networks,* **Best Poster runner up**: RESTART Plenary Dissemination Workshop, Palermo, Italy, 31.01.2025.

S. Quattropani, R. Di Natale, **F. de Trizio**, G. Sciddurlo, S. Rossitto, C. Caia, S. Gambadoro, G. Fontani, L. Paroli, M. Becattini, *Towards Communication Network Virtualization: Asset Administration Shell and AI-Powered Cloud to-Edge Integration for Realizing a Digital Twin of a Coherent Network,* **Best Poster winner**: RESTART Plenary Dissemination Workshop, Palermo, Italy, 30.01.2025.

S. Quattropani, C. Ricci, M. Becattini, L. Paroli, L. Scommegna, L. Pintor, G. Sciddurlo, **F. de Trizio**, L. Rachiele, *Coherent: introducing a reference architecture for digital twin networks,* **Best Poster winner**: RESTART Plenary Dissemination Workshop, Catania, Italy, 05.07.2024.

F. de Trizio, G. Sciddurlo, G. Piro, G. Boggia, *Optimizing Key Value Indicators in Intent-Based Networks through Digital Twins aided service orchestration mechanisms* **Best Poster runner-up**: RESTART Plenary Dissemination Workshop, Catania, Italy, 05.07.2024.

F. de Trizio, G. Sciddurlo, G. Piro, G. Boggia, *Effective Intent-based Service Provisioning via Network Digital Twins,* **Best Poster runner-up**: RESTART Plenary Dissemination Workshop, Bologna, Italy, 31.01.2024.

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