Adaptive Digital Twins for Wireless Networks through Frugal Metrology and Scalable Modeling

Level	Ph.D. Thesis
Keywords	Digital Twins ; Wireless Networks ; Performance Evaluation ; Network Modeling
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Duration	3 years, starting October 2026
Salary	∼ 2200 EUR gross per month

Modern wireless networks operate in highly dynamic environments, characterized by constant variations in radio conditions, traffic patterns, and node mobility. These dynamics make any attempt at precise and predictive network behavior modeling particularly challenging. While simulations remain an essential tool for design and performance evaluation, classical models struggle to capture the temporal and contextual variability of real environments.

To overcome these limitations, **Digital Twins** offer an innovative approach : they are virtual replicas of physical systems capable of remaining synchronized in real time through continuous data exchange. Applied to wireless networks, this concept paves the way for adaptive management in which the network becomes aware of its own state, capable of self-configuring and proactively optimizing its performance.

Recent work on Network Digital Twins (NDTs) has opened the door to dynamic digital representations of networks. Two major methodological families currently dominate the field [1] :

- **Physics-based approaches**, which rely on analytical models or high-fidelity simulations (e.g., ray tracing [2]) offering remarkable realism but at a prohibitive computational cost. Conversely, lighter models such as the Log-Distance Model provide faster computation at the expense of accuracy [3].
- **Data-driven approaches**, which rely on machine learning to model network behavior from real measurements [4]. Although promising, these approaches still suffer from three major limitations : (i) they rely on ideal and voluminous telemetry assumptions [5], (ii) they often adopt overly global network modeling by neglecting link heterogeneity [6], and (iii) they struggle to maintain accuracy in highly variable environments.

In this landscape, the thesis stands out through its clear orientation toward measurement frugality and scalable multi-level modeling. Rather than massively accumulating data, it aims to intelligently select and exploit the most relevant measurements to maintain a faithful representation of the network at minimal cost. It will also introduce a hierarchical modeling framework capable of dynamically adapting to changes in topology and load, while guaranteeing responsiveness compatible with online applications. More precisely, this work will revolve around two main axes :

1. **Frugal metrology** for traffic characterization : The thesis will propose adaptive telemetry me-

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chanisms combining passive observation and lightweight active probes, in order to obtain an optimal trade-off between accuracy, collection cost, and update latency.

2. **Scalable and fine-grained modeling of wireless links :** The thesis will develop a hybrid approach based on variable-granularity learning : wireless links will be dynamically grouped according to their statistical and topological similarities, allowing them to share predictive models while preserving fine-grained local descriptions. This approach aims to reconcile fidelity, scalability, and responsiveness.

The thesis will involve both technological and experimental research with strong scientific content, positioned at the intersection of dynamic systems modeling, intelligent telemetry, and learning applied to wireless networks. The expected contributions will support future developments in 6G networks, massive Internet of Things, and autonomous communication infrastructures.

Prerequisites :

— Hold a Master 2/Engineer degree (Bac+5) in computer science, electrical engineering, or a related field.
— Good understanding of networks, protocols, etc.
— Good understanding of artificial intelligence (regression models, neural networks, etc.) and its applications.
— Programming skills (Python, C).
— Good level of english (french is not required).
— Motivation and scientific curiosity.

Application :

Please send to samir.si-mohammed@univ-lorraine.fr your application file containing :

— A detailed CV,
— a motivation letter,
— a transcript of academic records.

Conditions & Selection Criteria

— The Ph.D. will take place at the CRAN laboratory (https://www.cran.univ-lorraine.fr/), affiliated with the University of Lorraine and the French National Centre for Scientific Research (CNRS). The salary is approximately 2200 euros gross per month.
— The position is funded through a Doctoral Contract from the University of Lorraine, **awarded through a highly competitive doctoral selection process**. Consequently, applicants must demonstrate **excellent academic performance and an outstanding academic record**.

Références

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[6] Samir Si-Mohammed and Fabrice Theoleyre. Per link data-driven network replication towards self-adaptive digital twins. In *IEEE MSWiM*, 2025.