Ph.D. in Information Technology
Thesis Defense

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Room Seminari Alessandra Alario - Building 21

Antonio BOIANO – XXXVIII Cycle

FROM DEVICE TO INFRASTRUCTURE: HOW TRAFFIC ANALYSIS ENABLES OBSERVABILITY IN ENCRYPTED AND HETEROGENEOUS NETWORKS

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Abstract:

Modern networks have shifted from static, hardware-centric infrastructures to highly dynamic, encrypted, and distributed ecosystems. This transformation improves agility, privacy, and scalability, but introduces significant observability challenges, creating a fundamental paradox: as networks become increasingly critical to society, their operation becomes less transparent and predictable. This thesis explores the role of traffic analysis as a lens for understanding these increasingly complex systems. Given the vast scope of modern networks and traffic analysis, we focus our investigation on specific use cases across three complementary scales of modern networked systems. At the device scale, we investigate traffic analysis for IoT forensic investigations, examining how the physical topology of IoT mesh networks influences traffic patterns. Our findings reveal that models trained under one network configuration may experience significant performance degradation when deployed in different topologies, despite having an identical device set. At the infrastructure scale, we examine how the evolution of Radio Access Networks challenges the temporal validity of traffic prediction models. We demonstrate that infrastructure changes systematically alter traffic distributions and invalidate the statistical relationships upon which predictive models depend. This reveals infrastructure evolution as a fundamental, yet underexplored, source of concept drift in network machine learning applications. At the learning-overlay scale, we analyze Federated Learning (FL) traffic from two perspectives: detection and characterization. We demonstrate that, despite encryption, the distinctive communication patterns of FL training can be identified from minimal observations, creating both opportunities for network-aware optimization and concerns about privacy. Through our FederNet platform, we establish an emulation framework for studying how algorithmic and optimization techniques in FL manifest as observable network behaviors. In conclusion, this thesis demonstrates that network observability through traffic analysis is challenged by heterogeneity, temporal drift, and non-stationary network conditions. To support the investigation of these limitations, we release datasets, measurement traces, and experimental platforms that address a critical gap in publicly available resources for studying model robustness under dynamic network environments.

PhD Committee

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