Ph.D. in Information Technology
Thesis Defense

September 21th, 2026
At 11:00 a.m.
Room Alessandra Alario - Building 21

Corrado INNAMORATI – 38th Cycle

ENHANCING MQTT FOR IOT: AN INTEGRATED APPROACH TO ANALYSIS AND OPTIMIZATION
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Abstract:

Recent advancements in the Internet of Things (IoT) have made connected devices an increasingly common part of modern digital infrastructures. These systems depend on lightweight communication mechanisms that allow resource-constrained devices to exchange information with local gateways and remote services. Among the available solutions, MQTT has become one of the most widely adopted protocols, mainly due to its publish/subscribe model, broker-based architecture, and suitability for telemetry-oriented communication. Besides the advantages that make MQTT attractive for IoT deployments, its practical use also exposes several limitations. Indeed, MQTT rarely operates in isolation. It is often embedded in heterogeneous systems where different communication models must coexist, where edge devices impose strict resource constraints, and where service continuity depends on the information maintained by the broker. For these reasons, improving MQTT-based systems requires a broader perspective than protocol-level optimization alone, combining the observation of real deployments with the design of mechanisms that support interoperability, constrained operation, and state management.

In this thesis, we consider the problem of enhancing MQTT-based IoT systems and explore multiple strategies and approaches to tackle it. Starting from an empirical scenario, we analyze MQTT deployments in the wild to understand how the protocol is effectively used outside controlled testbeds. This analysis considers publicly accessible brokers and investigates their behavior in terms of traffic volume, topic organization, payload representation, Quality of Service usage, and retained-message adoption. The results reveal that real MQTT usage is often lightweight, sparse, and highly heterogeneous, with a strong dominance of simple delivery semantics and a significant gap between recommended design practices and observed deployments. These findings provide a practical basis for the rest of the thesis, showing that MQTT optimization and extension should be guided by real usage patterns rather than only by idealized assumptions.

Then, we extend the analysis to the problem of interoperability between MQTT and REST-oriented protocols. Leveraging the insights gained from the empirical study, we propose broker-centric mechanisms that allow MQTT to interact with CoAP and HTTP while preserving the communication logic of the involved protocols. In this part of the work, MQTT topics are mapped to REST resources, publish/subscribe interactions are connected with request/response operations, and selected MQTT 5 mechanisms are used to preserve contextual information across protocol boundaries. First, we study this approach in a general-purpose broker environment through an MQTT--CoAP extension. Then, we move the same problem to a constrained scenario, designing and evaluating an ESP32-based MQTT--HTTP

gateway that integrates brokering, REST mapping, and metadata-aware communication inside a single microcontroller-class device. This second step highlights the practical limits of constrained interoperability, showing the role of bounded resources, admission control, and metadata handling in preserving stable behavior.
Finally, we address the problem of MQTT broker state and its role in dynamic IoT and edge environments. Since brokers are not only message routers but also maintain information required for service continuity, their internal state becomes relevant when systems must be migrated, replicated, or recovered. In this thesis, we analyze the internal structure of MQTT broker state, proposing a verified parametric model to describe state growth as a function of operational variables. We then use this model to study broker migration, decomposing the process into its main phases and evaluating how state size affects service interruption and client-perceived disruption.
Overall, this thesis provides a solid foundation for the analysis and evolution of MQTT-based IoT systems, addressing both the practical behavior of the protocol in real deployments and the technical challenges that emerge when MQTT is integrated, constrained, or moved across dynamic environments. We advance the state of the art by combining large-scale empirical observation with broker-centric interoperability mechanisms, microcontroller-class implementation, and explicit modeling of broker state. The proposed methods and architectures show how MQTT, already established as a de facto standard for IoT communication, can evolve beyond conventional telemetry exchange toward richer forms of protocol integration and continuity-aware operation.
We hope that these contributions will provide useful insights in this regard, fostering the development of more adaptable, interoperable, and continuity-aware MQTT infrastructures.

PhD Committee

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