From research to the industrialization of an IoT-Based RFID Solution for TARIP

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***Abstract*—This short paper presents the evolution and industrialization of an IoT-based RFID solution for waste tracking and pay-per-use taxation. The system enables the automatic identification, validation, and georeferencing of waste disposals through RFID technology, edge computing, and heterogeneous wireless networks. The paper describes the industrial architecture and reports the results of a real-world deployment in Benevento.**

***Index Terms*—IoT, edge computing, RFID, LoRaWAN, waste management**

I. INTRODUCTION

Smart waste management is one of the pillars of the smart city paradigm, aiming at making the waste life-cycle more efficient through updated regulation and mature enabling technologies. Along these lines, the Italian government has introduced TARIP[1], a new scheme for computing waste-related taxes. Following the current schema (TARI), the amount charged to each citizen is based on coarse indicators, such as the dwelling's surface area or the number of occupants. TARIP splits the bill into a fixed share, covering the service delivered by the waste operator, and a variable share, tied to the amount of unsorted waste each taxpayer has actually produced. Quantifying the variable share requires a mechanism to automatically measure the waste leaving each home.

Building on a previously validated research prototype [1], this work presents its evolution toward an industrial-grade system, deployed on waste collection vehicles, that tallies how many unsorted waste bags each citizen disposes of. The rest of the paper sketches the proposed architecture with its hardware and software components, and reports on an on-site trial carried out in Benevento.

II. RFID BASED WASTE TRACKING SOLUTION

The proposed solution relies on UHF RFID technology for the automatic and unique identification of waste disposals. Each unsorted waste bag is identified by a passive RFID tag uniquely associated with the relevant user; during collection, tags are automatically detected by reading devices installed on board the vehicles.

The architecture follows a distributed edge computing paradigm: a Pre-Processing Node (PPN) on each truck validates, filters, and georeferences the readings in real time, reducing the volume of transmitted data and ensuring operational continuity even under limited connectivity. The PPN also monitors the vehicle, including its position and estimated load level, and transmits both operational and detailed collection data to the central infrastructure through dedicated communication channels.

[1] Italian acronym for *TAssa sui RIfiuti Puntuale*.

III. PPN ARCHITECTURE

The PPN hardware is physically partitioned into two enclosures: the *Edge Logical Box* and the *Communication Module Box*. While the former can be installed anywhere on the vehicle, the latter hosts the antennas and must be positioned with an unobstructed view of the sky and minimal electromagnetic shielding, typically on the roof of the vehicle, to ensure reliable GPS reception and to maximize LoRa range and Wi-Fi connectivity.

The Edge Logical Box (Fig. 1) integrates the core computational and control components: an industrial Edge Computer running the PPN application software, a UHF RFID reader, an ESP32 microcontroller managing the power state of the PPN by detecting the vehicle ignition and shutdown signals, and power distribution circuitry.

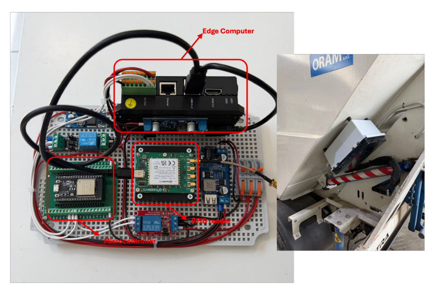

Fig. 1. Edge Logical Box

The Communication Module Box hosts the radio-frequency devices: a LoRa module for low-bandwidth transmission of vehicle status information, a GPS receiver for real-time geolocation, and an external Wi-Fi antenna that extends the connectivity of the Edge Computer for high-bandwidth transmission of detailed stored data.

The RFID reading antenna is installed on the end wall of the truck's tank, oriented toward the delivery area, to maximize coverage and reading reliability. Since the antenna operates within the compactor's environment, characterized by vibrations, impacts, and mechanical stress, a dedicated protective shield was designed and built. The shield provides mechanical protection against impacts and continuous vibrations while preserving the radio performance of the system, through a geometry and material selection that avoids shielding or interfering with the RFID signal.

The Edge Computer runs a multi-threaded Java application whose main modules are shown in Fig. 2. The *PPNManager* coordinates the overall processing, relying on dedicated modules for the onboard peripherals: the *RFIDReader* and the *GPSReceiver* acquire and normalize tag readings and position data, filtering out spurious, inconsistent, or duplicate readings, while the *GPIOManager* detects the vehicle shutdown signal to safely terminate the application. Each valid reading is georeferenced with the temporally closest GPS coordinates and handed to the *Data Persistence* layer, which stores positions, disposals, and tag samples while waiting for cloud connectivity. The vehicle load is continuously estimated by counting uniquely validated readings, and the *LoraManager* periodically transmits summary information on position and load through the LoRaWAN network. Finally, the *NetworkMonitor* checks cloud connectivity and, when available, triggers the upload of the detailed stored data to the TARIP services in the Cloud.

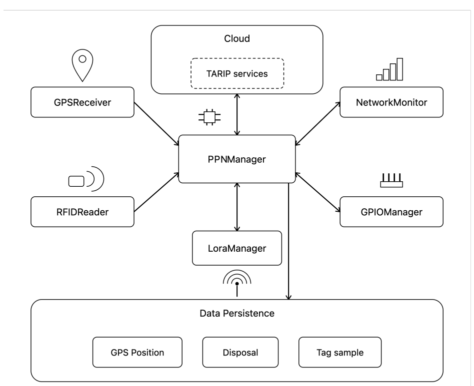

Fig. 2. PPN Software Architecture

IV. EXPERIMENTATION

For validation, the system was deployed in a real operational environment, in the Rione Ferrovia district of Benevento, involving approximately 1,300 taxpayers, including domestic, non-domestic, and industrial users. The operational fleet consisted of 31 waste collection vehicles equipped with the proposed IoT architecture while the experimentation was conducted on a subset of 11 vehicles selected from the fleet.

Data communication was performed following a dual-channel model. Detailed information on individual disposal events, including RFID readings and associated metadata, was locally stored on the vehicle and transmitted via Wi-Fi when the truck was within range of the access point, enabling the transfer of high-volume datasets without constraints on network availability during collection. Conversely, LoRa was used for the periodic transmission of lightweight operational information, such as the current position and the truck load level, enabling low-power-consumption continuous monitoring of fleet status and collection progress over large areas.

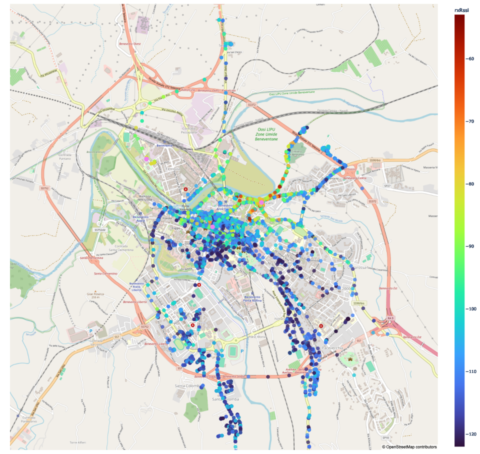

Fig. 3. RSSI map of the LoRaWAN uplink messages

The experimental activities evaluated the identification of the vehicles involved during the waste collection, the recording of the routes performed, the georeferencing of the disposal operations and their integration with RFID data, and the transmission / visualization of the collected information through monitoring tools. The deployment was supported by a LoRaWAN infrastructure previously developed by researchers of the Department of Engineering of the University of Sannio: three LoRaWAN gateways, equipped with high-gain antennas exceeding 2 m in height, were installed in different areas of the city and configured in a mesh topology, enabling the use of a network server installed directly on the gateways.

Fig. 3 shows the georeferenced map of the LoRaWAN uplink messages transmitted by the ASIA Benevento vehicles, whose identification codes are reported in the legend, during the experimental activities. Each colored marker corresponds to a message received by the LoRaWAN infrastructure at the GPS position of the transmitting vehicle, with the color representing the received signal strength (RSSI), while the pink markers represent the three LoRaWAN gateways. The received signal levels, mostly ranging between -60 and -120 dBm across the whole urban area, confirmed the capability of the deployed LoRaWAN infrastructure to support the expected operational requirements. Further data about the experimentation will be discussed during the presentation, due to the limited space of this abstract.

ACKNOWLEDGMENT

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REFERENCES

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