Demo: Enhancing LoRaWAN Networks with Edge Computing: A Demonstration on a Large-Scale Scenario

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ABSTRACT

The rapid growth of the Internet of Things (IoT) and the emergence of Low Power Wide Area Network (LPWAN) technologies, such as LoRaWAN, have revolutionized how applications and services can leverage sensor and actuator devices. This paper demonstrates the framework with two new enhancements that enable the LoRaWAN system architecture to support edge processing capabilities in a large-scale urban scenario with mobile devices. The demonstration showcases the adaptability and load balancing capabilities of the resulting system, allowing seamless transition handover between edge nodes. The framework operates within the traditional LoRaWAN architecture, ensuring backward compatibility, and introduces an automatic traffic flow management system based on real-time resource monitoring. We use the LoRaMC dataset to highlights the effectiveness, scalability, and robustness of the proposed system, showcasing the integration of edge processing capabilities into the LoRaWAN architecture for improved data processing and system performance in the city-scale scenario.

CCS CONCEPTS

• **Networks → Network design principles**; • **Security and privacy**; • **Computing methodologies → Distributed computing methodologies**;

KEYWORDS

IoT, LoRaWAN, Edge-to-Cloud Continuum

1 ENABLING EDGE PROCESSING OVER LORAWAN DEPLOYMENTS

The Internet of Things (IoT) is continuously expanding by creating new possibilities for modern-day large-scale applications and services. Today, Low Power Wide Area Network (LPWAN) represents one of the most rapidly deployed long-range communication architectures to facilitate large-scale connectivity among IoT devices, potentially reaching a staggering 22 billion connections by 2025 [1]. At the same time, the global volume of data generated from IoT devices will reach an astonishing 175 zettabytes by 2025 [2] creating an enormous need for a massive data transfer rate and guaranteed low latency requiring a paradigm shift from the traditional cloud-centric producer/consumer model. Recently, a new paradigm was introduced called cloud edge computing continuum (CECC) that works towards evolving the more traditional central cloud/data-center with ultra-high-end processing powers and high-capacity networking infrastructure to extend their coverage all the way to the network edge, and thus driving a significant transformation also in the IoT field, contributing to the processing of data closer to the points of generation and need, resulting in improved response times and reduced bandwidth usage.

We look at LoRaWAN (Long Range Wide Area Network), a cloud-centric technology designed for wireless battery-operated things [3] in combination with , a framework that allows the integration of LoRaWAN into the CECC paradigm by incorporating edge and far-edge resources in LoRaWAN deployments [4]. This is achieved by introducing an enhanced version of LoRaWAN that transforms LoRa gateways (GW) from simple bridges to edge processing units in a secure and privacy preserving manner. The proposed design relies on the association of IoT end-devices (ED) to a specific CECC-native GW that will serve as the intermediate point for processing and storage in the CECC. The resulting system ensures backward compatibility for seamless interoperability between legacy and new elements without disrupting network operation and providing quality of service guarantees.

We here introduce and demonstrate two new mechanisms for that allows to seamlessly process data produced by CECC-native ED by a CEEC-native GW even when the ED is not within the coverage of the GW due to mobility. The first mechanism forwards frames to the associated GW in the case when the ED is not within the coverage, while the second mechanism allows the handover of an ED from one GW to another based on the current network conditions and application-level parameters to optimize the available network, processing and storage resources.

Fig. 1 depicts the extensions to the framework indicating the data flow within the system via multiple paths. Standard routes are used for regular traffic, while for enabled EDs, data access within the frames is made possible through the establishment of a group key involving the cloud (AS), edge (GW), and ED. The processing of flows is performed either at the receiving GW, if it is the one associated with the ED, or otherwise, traffic is redirected to the associated GW, as indicated in Fig. 1 by the black arrow, and eventually to the AS after being processed. Our mechanism introduces an automatic traffic flow management system. It is based on real-time monitoring of resources in terms of radio coverage and computational capacity, enabling the redirection of traffic flow from one GW to another without the need to pass through the central server.

To evaluate the scalability of the proposed extensions of in large-scale urban scenarios, we use LoRaMC, a new dataset specifically designed for the evaluation of IoT systems with 3300 EDs moving within a 200 square kilometer area. We demonstrate how to

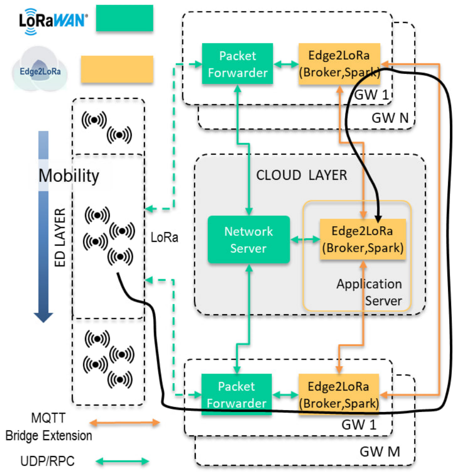

Figure 1: system architecture and possible routes in the mobility scenario.

perform edge processing on LoRaWAN utilizing Apache Spark [1], enabling the CECC-enabled GWs to execute stream-based big data queries. Thus the traffic is automatically processed by different GWs (edge nodes) as the EDs change location within the city. The demo demonstrates the dynamic and adaptable nature of the system, thus, we present the forwarding mechanism, and the load balancing reassignment, including the transition hand-over from one GW to another.

2 RUNNING DISTRIBUTED APPLICATIONS

We implement two distinct applications to demonstrate the benefits of the proposed approach for integrating edge resources in a big data analytics framework. The first application is related to the management of the network and targets network operators while the second one is connected to the monitoring of the transportation infrastructure targeting city administrators. Both applications process the sensor values received through the LoRaWAN packets using the resources available at the gateways, that is the edges of the network, based on a combination of stream-based big data query operators. The first application calculates the average of the Received Signal Strength Indicator (RSSI) over a predefined time interval that allow to better allocate devices, e.g., across the spreading-factors of the medium. The second application utilizes a Hampel filter to identify anomalies/outliers in real-time on the velocity of the vehicles to identify areas of congestion on the transportation network. This dual-application setup showcases the system's versatility in handling both basic signal metrics and complex data analytics tasks.

Network Resource Monitoring: The big data query processes frames containing RSSI values and computes their average within a predefined time window and for each device address, allowing the network operator to fine-tune the performance of the network per each individual device. The aggregated data is then forwarded to the , providing concise reduction of data transferred via the network backbone.

[1]https://spark.apache.org

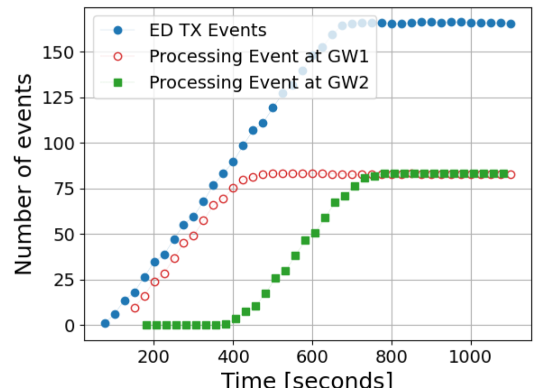

Figure 2: System performance over the distributed application execution. ED transmission events at each as the number of progressively increases.

Real-time Anomaly Detection: A Hampel filter is applied for the anomaly detection of the sensor values. This robust outlier detection technique analyzes the sensor streams within a moving window to identify outliers in real-time and provide alerts on potential incidents on the transportation network. The sensor values are thus aggregated to single events that are directly forwarded to the .

Fig. 2 illustrates the number of transmissions from EDs within a 5-second window and the corresponding number of processing events handled by each GW within the same time frame. This highlights the system's ability to dynamically adapt to changes in the network while efficiently distributing the workload across multiple GWs, maintaining balanced resource usage, and ensuring consistent performance. In this scenario, two GWs are co-located, with end devices in their coverage area beginning transmissions at staggered intervals. A simple load-balancing algorithm is employed, which assigns devices to GWs based on the number of devices associated with each gateway and the average load on hardware resources, such as CPU and memory. This approach results in roughly half of the devices being assigned to one GW and the other half to the second GW, balancing the processing load between the two.

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