Work in Progress: Enhancing Sewage Systems Monitoring Through the Integration of Optical Fibre Sensors in IoT

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***Abstract*—Efficient monitoring of sewage systems networks and their pump stations is vital to avoid environmental spills and enhance customer safety. This paper proposes the integration of optical fibre sensors (OFSs) into an Internet of Things (IoT) platform for better monitoring of such sewage networks. The work addresses key challenges such as scalability and interoperability of an IoT platform that supports seamless OFS-to-Cloud connectivity. The proposed platform leverages compression algorithms and edge devices to optimize data communication. This platform is based on 28 different OFSs that have been set up in a laboratory environment to simulate a similar set up in a sewage network. This work achieved 50% compression ratio for the data collected from the OFSs and Amazon Web Services (AWS) S3 cloud system is used for data storage. This work is conducted in collaboration with Sydney Water.**

Keywords—Optical Fibre Sensor (OFS), Internet of Things (IoT), IoT Sewage monitoring, cloud-based platform.

I. Introduction

Environmental monitoring is of critical importance today. Industrial operations and residential areas can have adverse environmental impacts, especially on straining the sewage systems. Efficient monitoring and management of these systems allows for complying with the relevant regulations and mitigating the risks on the public health. Unfortunately, discharges of treated and untreated sewage result in adverse consequences such as poor water quality from pathogens, eutrophication from nutrient loadings, and toxicity to humans and ecosystems from various chemicals [1]. Additionally, sewage discharges cause the accumulation of contaminants in organisms and sediments and alter biological communities due to physical and chemical disturbances [1]. By leveraging the relevant sensor technologies, better monitoring of the sewage system can be achieved such that relevant actions can be taken, which benefits the environment and leads to better customer satisfaction. An integration among sensor technologies, machine learning (ML), and the Internet of Things (IoT) can lead to Smart Environmental Monitoring systems [2]. Through the deployment of a wireless sensor network, an IoT platform can effectively monitor an environmental phenomenon with least human supervision. The data collected by the sensor nodes can be communicated to a cloud service for further processing, analysis, and storage. Furthermore, a user interface can be employed to access the data stored on the cloud and manage or control the sensor nodes and the cloud server. In other words, the IoT platform is constituted by the sensor nodes, the user interface, the cloud service, and the connectivity technology used to connect these three components together.

The use of an IoT platform to achieve the monitoring task of sewage systems is the main objective of this work. In particular, we develop an IoT-based monitoring system that leverages optical fibre sensors (OFSs) to better collect data from the *harsh* conditions typical in sewage pipelines. As such, our contributions in this paper are:

1. Creating a novel OFS-to-Cloud IoT platform that connects the OFSs to a cloud service that can analyze and store the data communicated by the OFSs. A testbed is set up to

Figure1. Testbed for the OFS-to-Cloud IoT Platform

simulate this IoT platform. This testbed employs data compression techniques to achieve timely communication while guaranteeing a scalable, interoperable, and cost-effective platform.

2. Studying the entire journey of data from OFSs to the cloud so that bottlenecks that hinder scalability can be identified.

The rest of the paper is organized as follows. Section II covers the related work. Section III describes a novel testbed for OFS-to-Cloud IoT platform. Section IV describes the implementation and evaluation of the testbed and the future work. Finally, Section V concludes this work.

II. Related Work

In this section, we review both IoT systems to monitor sewage systems, and systems for OFS-to-Cloud communication.

Rony et al. in [3] presented a layered IoT monitoring system that utilizes a water level sensor to monitor blockage. Sikorski et al. in [4] proposed an IoT monitoring system that measures chemicals and detects blockage in pipelines. Fares et al. in [5] presented a real-time, layered IoT system for detecting sanitary sewer blockage using ultrasonic level sensors. Bhosale et al. in [6] introduced a sanitary sewer overflow detection IoT system consisting of ultrasonic sensors, gas sensors, Raspberry Pi as an edge device, and "ThingSpeak" as a cloud platform. Li et al. in [7] presented a sewer blockage identification system based on liquid level sensor connected to a cloud server for analysis. Zhu et al. in [8] presented an IoT system for monitoring wastewater and sewage pipes consisting of a monitoring layer, a middle layer, and a field executive layer. Salem et al. in [9] presented an IoT real time monitoring system developed for wastewater treatment using a NodeMcu ESP8266 microcontroller as an edge device that is connected to a local server via HTTP protocol. Kumar et al. in [10] proposed an IoT monitoring system for wastewater treatment consisting of a water quality sensor, a pressure sensor, and a temperature sensor that are connected to a cloud server via HTTP. Martínez et al. in [11] presented a low cost IoT system for water quality monitoring consisting of a portable ion chromatography (IC) system, and Raspberry Pi Zero for data logging and analytics. Hong et al. in [12] introduced a layered IoT monitoring application for sewage treatment. Wang et al. [13] demonstrated a cloud-based platform that consists of five layers, namely, the infrastructure layer, the data resource layer, the application support layer, the user layer, and the decision layer, that utilizes OFSs for measuring temperatures and strains. Cennamo et al. [14] illustrated the use of an IoT system that connects OFSs to a server, with a data acquisition component. Gomes et al. in [15] presented an OFS connected to the cloud for monitoring respiratory frequency using a smartphone for data collection and data analysis on edge.

While our review shows that the use of IoT platforms for monitoring sewage systems is not a new approach, and even though researchers have highlighted the benefits of utilizing OFSs for monitoring purposes in harsh environments, we observe the following gap, which forms the main motivation behind our project:

The lack of works that create an OFS-to-Cloud communication system as an IoT platform to support monitoring applications, such as sewage system monitoring, taking into consideration the requirements of scalability, interoperability, and robustness.

III. Testbed for OFS-to-Cloud IoT Platform

OFSs have been widely studied for conventional structural health monitoring due to their multiplexing capabilities and their resistance to environmental interference [16]. The research published on OFS-to-Cloud communication provides valuable insights on the ability of cloud servers to manage the data produced by these sensors. However, the literature lacks the focus on how to optimize OFS-to-Cloud communication from a *system's* perspective. That is, there is a need to look at the full journey of the data through the entire OFS-to-Cloud system; starting with data collection by OFSs, then data formatting in preparation for communication, reaching the cloud server for analysis and decision-making, and ending with data storage in the cloud. The system's perspective allows for a more elaborate look at all the stages involved in the OFS-to-Cloud communication. This allows for recognizing any bottlenecks that may deteriorate the overall performance and help in achieving a more scalable platform. Towards that objective, we introduce the testbed for the OFS-to-Cloud IoT Platform that is shown in Figure 1. The testbed consists of OFSs, an edge device, the Amazon Web Services (AWS) IoT server, and AWS S3 Bucket. The OFSs collect monitoring data and pass them to the edge device. The latter compresses the data and transfers them to the AWS IoT server. Finally, the IoT server stores the received data in the AWS S3 Bucket based on topics (as explained shortly).

In transferring the collected data from the OFSs to the AWS IoT server the Message Queuing Telemetry Transport (MQTT) protocol is used. MQTT is a widely adapted application layer protocol in IoT, and it is very reliable for machine-to-machine communication. The available research on OFS-to-Cloud communication solely uses the HTTP protocol, which follows the request-response mode of communication. MQTT, however, uses the publish-subscribe mode of communication. In the request-response mode, the communication happens between a client (that sends requests) and a server (that replies with responses). This mode results in a strong coupling between the client and the server, and that obstructs scalability. On the other hand, the publish-subscribe mode achieves the decoupling between the publishers and the subscribers. In this mode, the publishers publish the data into a server that categorizes the data into topics. Subscribers subscribe to these topics and get notified whenever an update happens to their respective topics. That is, there is no coupling between the publishers and the subscribers. In fact, publishers do not even know about the availability of the subscribers and the subscribers are only interested in the data in the topics without the need for the publishers to be available or reachable. Based on that, the publish-subscribe mode is highly scalable compared to the request-response mode and it achieves our aforementioned objective in building the OFS-to-Cloud testbed. Also, being a standardized protocol that is deployed widely in IoT systems, MQTT allows for the design of an interoperable testbed.

As mentioned earlier, the edge device compresses the data it receives from the OFSs. Data compression is used to support system's scalability. A mix of compression algorithms are used in this testbed. Delta encoding is used to reduce data redundancy while switching character mechanism is used to reduce the size of the data (by changing the readings into characters) while supporting security. Details of the actual implementation of the testbed are provided in the next section.

IV. Implementation and Evaluation of the Testbed

The testbed in Figure 1 has been implemented in a laboratory environment with 28 OFSs. The OFSs have been realized by Fibre Bragg Grating (FBG)-based devices (this design has been applied before by some of the authors to create a number of different sensor types [16]). The versatility of the FBG-based design is emphasized in our implementation. Depending on how they are configured, FBGs may monitor different types of parameters such as temperature, strain, or pressure. The edge device has been realized by a Micron Optics® HYPERION si155 interrogator. This interrogator has 4 channels. Each channel can be used to connect several FBGs. The interrogator is connected to Raspberry Pi 4 through an ethernet cable. In the current stage of this project, we report the impact of using data compression in the testbed. Three compression algorithms were tested to check their compression ratio, namely, LZ4, Zlib, and Brotli. The compression ratio of each algorithm was tested on 44 sensors that generate data every 10 seconds. The achieved compression ratios were 43.7% for LZ4, 68.8% for Zlib, and 71% for Brotli. Due to its high compression ratio, Brotli lossless compression has been selected for deployment in our testbed. Before applying Brotli, Delta encoding and switch character mechanism are used. The OFSs generate data with a frequency of 2 Hz, that is, 2 readings per second for 28 OFSs. Each reading is of size 585 bytes. Therefore, the data produced is 4.02 MB/hr, which is equivalent to almost 96.44MB /day or 34 GB/year. In testing this approach, each 7 readings produced by the 28 OFSs in our testbed of size of approximately 4 KB (4096 bytes) are compressed by the sequence of Delta encoding, switch character, and Brotli compression allowed for reducing this size to 2.047 KB (2096 bytes). This is a reduction of almost 50% in data size. The compression ratio increases when the number of sensors increases. Through developing a Python-based tool to download the data from the AWS S3 Bucket and decompress it, the original data was restored successfully. Therefore, with this reduction in data size the testbed offers an opportunity to enhance storage efficiency, reduce bandwidth usage, and achieve cost-effective OFS-to-Cloud system. This is an important step towards supporting scalability.

In our next stage, we will work on a rigorous evaluation of our testbed by deploying it in the water network of Sydney Water, Australia. This will help in testing the scalability, interoperability, sensor failure management, and the speed of data analysis and decision-making at the cloud. Furthermore, we will explore the value of applying machine learning algorithms on the collected data for better predictions on maintenance requirements of the sewage system.

V. Conclusion

This work explores the integration of OFS and IoT to build an OFS-to-Cloud IoT platform for the purpose of monitoring sewage systems. This work addresses the research gap seen in the literature in that no works look at the entire journey of the monitoring data from collection to analysis and storage. Our aim is to build an IoT platform that is both scalable, interoperable, and, as a result, cost-effective. Towards that, we have built a novel testbed for an OFS-to-Cloud IoT platform that leverages both data compression and the MQTT. As an initial stage, our testbed achieves almost 50% reduction in the size of the collected data collected. This work is in collaboration with Sydney Water, Australia, with the aim of improving the monitoring system of their network.

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