APPLICATION OF SERVERLESS SYSTEMS FOR PROCESSING METROLOGICAL METADATA IN IOT

Oksana Honsor, Cand. Sc. (Tech), As.-Prof., Oleksandr Demidov, PhD Student,
Lviv Polytechnic National University, Ukraine;
e-mails: oksana.y.honsor@lpnu.ua, oleksandr.s.demidov@lpnu.ua

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Abstract. The article investigates the potential of serverless architectures for efficiently processing large-scale metadata generated by Internet of Things (IoT) sensors. As IoT systems grow increasingly complex, the challenges associated with processing vast amounts of data in distributed environments become more pronounced. Key issues include ensuring data accuracy, maintaining scalability, and reducing the operational costs of data processing infrastructure. The paper proposes serverless computing as a highly adaptable solution to these challenges, focusing on its capacity for real-time processing, dynamic scaling, and seamless integration with modern cloud platforms. The research highlights the importance of dynamic calibration of IoT sensors to ensure the accuracy and reliability of collected data. Dynamic calibration addresses challenges such as environmental changes and sensor degradation, leveraging serverless systems to automate recalibration based on real-time data analysis. The authors propose an architecture based on Amazon Web Services (AWS) to demonstrate the practical application of serverless principles. This architecture incorporates AWS Lambda for computational tasks, SQS for workload distribution, and S3 for scalable data storage.

The article emphasises the advantages of serverless systems, including cost-efficiency, resource optimisation, and scalability, while acknowledging challenges such as secure integration of private data and potential errors in automated systems. The authors argue that, with proper implementation, serverless architectures can provide robust solutions for IoT metadata processing, enabling improved performance, reliability, and economic efficiency in modern IoT ecosystems.

By addressing both theoretical and practical aspects, the study offers valuable insights for researchers and practitioners seeking to harness the power of serverless systems for IoT applications. The findings underscore the transformative potential of cloud-based, serverless infrastructures in achieving efficient and scalable data management for IoT-driven industries.

Key words: Internet of Things, sensor network, data processing, serverless systems, digital calibration.

1. Introduction

The processing of data in Internet of Things (IoT) systems is associated with a number of specific challenges that arise due to the distributed structure, the large number of connected devices, and the limited computing resources. The Internet of Things generates vast quantities of metadata from sensors that contain information about location, time, state, and measured environmental parameters [1-3].

The dynamic calibration of sensors in Internet of Things (IoT) systems represents a crucial aspect of ensuring the accuracy and reliability of the data obtained. This is particularly pertinent for systems operating in complex or variable environments, where measurement accuracy may fluctuate over time due to the physical deterioration of sensors, alterations in the surrounding environment, temperature changes, or other variables.

Serverless systems are well-suited to processing such data due to their capacity for automatic scaling, real-time event processing, and low infrastructure costs. The deployment of serverless systems for processing sensor metadata in the context of the Internet of Things (IoT) represents a promising avenue of research, as it allows for the development of an efficient, flexible, and cost-effective infrastructure for processing large amounts of data.

2. Drawbacks

In order for the data collected by IoT sensors to be helpful in the context of an automated system, it must undergo several processing stages. At the post-processing stage, a system is required that will perform a number of operations, including storage, conversion to a unified format, analytics, generation of results, and transfer to third-party services for further use (e.g., machine learning models). Implementing these functions can be complex when dealing with a large amount of input data, requiring significant resources. The main requirements for sensor data in IoT are accuracy and reliability, which are ensured by dynamic sensor calibration [4].

Dynamic sensor calibration is the process of automatically adjusting and correcting sensor settings in real-time or according to a specific schedule, obviating the necessity for manual intervention. This approach facilitates enhanced measurement precision, even in the context of evolving operational circumstances. A considerable number of dynamic calibration systems incorporate feedback mechanisms whereby the system analyses the collected data, identifies any inconsistencies or deviations, and then automatically adjusts the settings. Dynamic calibration can be conducted by utilising cloud-based services that collect data from disparate sensors, analyse it, and subsequently issue calibration directives. The cloud allows for the storage of large amounts of data and the execution of complex calibration calculations that may be challenging to perform at the individual sensor level. Cloud services and serverless systems are closely related, as serverless systems represent one type of service that can be provided through the cloud. They are united in that both concepts utilise cloud infrastructure for data processing, computing and application management but differ in terms of the underlying principles of operation and approaches to resource management [5].

There are numerous models and tools for developing such a system, but the serverless architecture is the optimal choice. This approach is the most suitable for data processing in IoT systems due to its distinctive characteristics, particularly: scalability, high reliability, cost-effectiveness, noise immunity, and the capacity to integrate with diverse services that enhance system performance (logging, machine learning, data warehouses, etc.). [6].

3. Goal

The goal of the article is to explore and analyse the potential benefits and challenges of using serverless architectures to handle metrological metadata efficiently. This article aims to provide insights into how serverless systems can support the scalability, flexibility, and cost-effectiveness needed for processing large-scale metrological data, which is essential for real-time monitoring, data standardisation, and interoperability in various industrial and scientific applications. By examining specific use cases, best practices, and limitations, the article seeks to offer practical guidance for implementing serverless solutions tailored to the unique requirements of metrological data processing in the Internet of Things (IoT) environment.

4. Integration with a serverless system for processing, modifying, and analysing the received data

4.1 Features of serverless systems in IoT

Serverless computing represents a model of computing wherein developers are able to write and execute code without having to concern themselves with the management of servers, the configuration of infrastructure, or the scaling of resources. The serverless computing approach involves the automatic deployment and execution of functions or applications on the cloud provider's infrastructure, with resources automatically scaled to meet the required load.

Typical IoT systems consist of three major layers: data collection, transmission, and analytics, as shown in Fig. 1 [7].

The data collection layer is comprised of IoT end devices that are used to detect, collect, and store sensor data. IoT devices can form sub-systems, like smart homes and Intelligent Transportation Systems (ITSs). IoT end devices and sub-systems are the fundamental and core components of IoT systems, which directly interact with their physical IoT environments through sensors and actuators. The transmission layer is enabled by gateways to transmit data between IoT end devices and edge/cloud servers. Common transmission strategies include cellular networks, Wireless Fidelity (WiFi), Bluetooth, Zigbee, etc. The analytics layer is responsible for processing and analysing data from IoT devices, which can be completed in both cloud and edge servers.

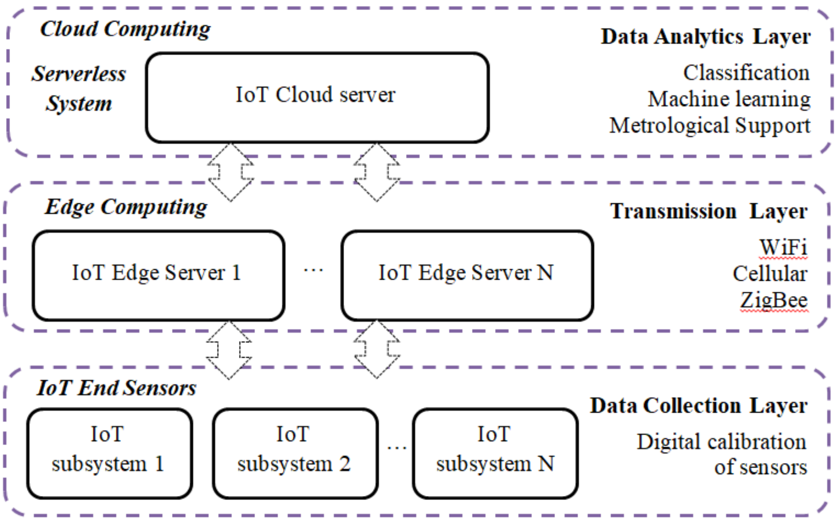

Fig. 1. An overview of IoT data analytics architecture

Serverless systems are powered by cloud services, with numerous cloud providers, including Amazon Web Services (AWS), Microsoft Azure, and Google Cloud Platform (GCP), offering services for developing serverless applications.

Serverless systems can be utilised for the processing of Internet of Things (IoT) metadata in the following key areas:

1. Real-time data analysis. Serverless features facilitate the detection of trends or anomalies in data in real time. This is advantageous for monitoring systems that require a rapid response to thresholds or other significant events, such as changes in temperature or humidity.

2. Aggregation and filtering of sensor data. Internet of Things sensors are capable of generating high-frequency data, which often necessitates filtering or reduction to more generalised metrics. Serverless functions can aggregate this data and transmit only the requisite information to the database, such as averages or filtered events.

3. Dynamic sensor calibration. Serverless functions can be employed to dynamically adjust sensor calibration based on historical data or changes in environmental parameters. The functions can be utilised to trigger recalibration procedures, log changes, and issue warnings regarding the necessity for maintenance.

4. Manage metadata storage and access. Serverless functions are capable of classifying, filtering, and storing metadata in defined database structures or data lakes. This enables the efficient organisation of access to data for further analysis or archiving.

5. Guarantee security and compliance. It is imperative that IoT data be processed in accordance with established security and privacy standards. Serverless functions can verify the compliance of metadata streams with security policies, encrypt sensitive data, and automatically respond to suspicious events [8, 9].

4.2 Development of a serverless system architecture for processing information from sensor IoT

The utilisation of AWS cloud resources offers a plethora of functions and services that facilitate a multitude of system operations. As illustrated in Fig. 2, the proposed set of services and resources employed in constructing a serverless architectural solution are delineated, along with the associated connections, data transmissions, and rationale.

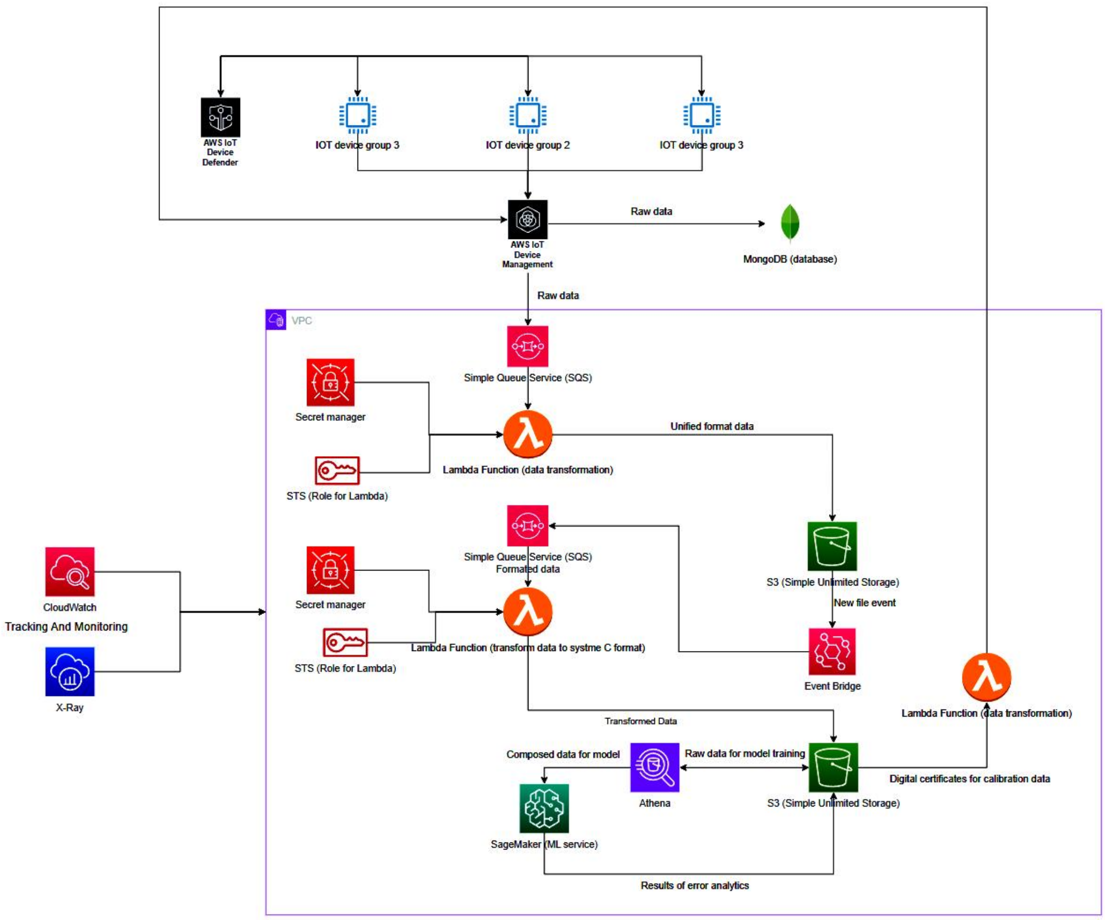

Fig. 2. Proposed architecture of a serverless system for processing information from IoT sensors

1. The processed data is transferred to S3, a cloud data storage system that offers a high degree of capacity and is integrated with a range of other services. To illustrate, once the data is in S3, the Event Bridge service monitors changes in a specific folder and notifies the subsequent stage, which in turn calls the Lambda function. However, this is not for data processing but rather for analysing the data and creating datasets from it for the machine learning model. At this stage, the data will be transferred to system C. It is noteworthy that each Lambda function has a Secret Manager and STS (a role for the lambda). This enables the transfer of secret keys (for instance, for database writing or third-party analytics resource communication) and a role that determines the services to which the function will have access.

2. Following the data analysis and its conversion to a data network, it is returned to S3, where it can be collected using Athena. This tool enables the execution of SQL queries on S3 files as if they were a relational database, provided that a schema is available. Subsequently, the network data is transferred to the Sagemaker machine learning model, which serves as the container for the model's computations. This step is optional, as the system may not utilise machine learning but rather employ data analytics through a specific algorithm.

3. Subsequent to the receipt of the machine learning results, the ultimate data are written to S3. After that, they are conveyed to the concluding Lambda function, which only writes to assorted dependent systems. This may entail the creation of documentation or the calibration of sensors, contingent upon the information received or the error.

4.3. Advantages and disadvantages of the described architectural solution

The proposed architectural design offers a number of significant advantages, which will be discussed in the following paragraphs. In general, the disadvantages are more specific to the particular circumstances of each individual situation. Nevertheless, the principal shortcoming is the integration of cloud resources. This entails the potential for security breaches when sending and verifying input data for calibration. For this architectural approach to be practical, it is essential to have a clear understanding of the types of data that will be included in the analytical phase and to ensure the secure delivery of this data if it is private. This can be achieved through a number of methods, including the use of a private network, a virtual private cloud without an Internet Gateway running on Output, and others [11-13]. Additionally, automated sensor calibration based on analytical data is inherently uncertain due to the potential for errors in both the processing stage and the analytical or machine learning model. To fully automate this process, a system for detecting interference and verifying the results (potentially through repeated data processing) must be developed.

Nevertheless, the advantages to be derived from the appropriate implementation are manifold. In terms of security, the information stored in the cloud and the processing of that information will be protected by many security indicators. These include the provision of private keys, the use of a separate virtual private cloud (VPC), a monitoring and error detection system, and a system of roles and access controls. Furthermore, the potential for expansion and efficiency is considerable. In addition, the system allows for the allocation of an unlimited number of resources for data storage and computing.

Conversely, these resources are only operational when new data is introduced, thereby ensuring the system's cost-effectiveness. The process orchestration functionality enables the clear delineation of work stages, facilitating the monitoring and analysis of these stages, as well as the identification of potential errors or areas for improvement. Furthermore, AWS offers seamless integration with IoT devices, providing services, security, and control over groups of IoT devices. These include AWS IoT Device Management and AWS IoT Device Defender.

4.4. Prospects for further research

Considering the advantages and disadvantages mentioned above, as well as the availability of the initial architectural prototype, it makes sense to continue research based on practical application. Cloud integration of such a system is not a trivial task and involves many variables and factors that may alter the architectural approach during implementation or based on the results of practical research. The main directions for further research will include:

1. Exploring possible methods of data transmission between the IoT system and the cloud. This step encompasses both theoretical exploration for the best solution and its implementation, as well as deriving conclusions through stress testing and white-hat hacking of the system.

2. Finding the optimal method for sensor calibration and an algorithm for preventing random errors. This step is crucial as it affects the overall system’s reliability. Mechanisms for validating data before calibration must be robust. This can be achieved through various means, including implementing a machine learning model to verify received data and detect errors.

3. Evaluating the effectiveness of the developed system. To assess the effectiveness of the proposed solution, it should be compared with similar competitors,

other architectural approaches, and alternative implementation options. This involves identifying the strengths and weaknesses of each solution.

5. Conclusions

The utilisation of a serverless architecture for the processing of sensor metadata in Internet of Things (IoT) systems enables the resolution of issues pertaining to scalability, cost-effectiveness and reliability. The proposed solution, based on AWS cloud resources, provides dynamic sensor calibration, real-time operational analytics, and efficient organisation of ample data storage and processing. Despite certain challenges related to the security and integration of private data, this architecture demonstrates high flexibility, resource efficiency and scalability, making it a promising solution for modern IoT solutions. Thanks to its automation, orchestration and monitoring capabilities, this architecture can form the basis for a reliable metrological metadata management and processing system in environments requiring high accuracy and reliability.

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References

[1] Eichstädt, S. (2020, June). From dynamic measurement uncertainty to the Internet of Things and Industry 4.0. In *2020 IEEE International Workshop on Metrology for Industry 4.0 & IoT*, pp. 632-635. IEEE. DOI:https://doi.org/10.1109/MetroInd4.0IoT48571.2020.9138250.

[2] Schneider, T., Helwig, N., & Schütze, A. (2018). Industrial condition monitoring with smart sensors using automated feature extraction and selection. *Measurement Science and Technology*, *29*(9), 094002. DOI:https://doi.org/10.1088/1361-6501/aad1d4

[3] S. Hackel, F. Härtig, T. Schrader, A. Scheibner, J. Loewe, L. Doering, B. Gloger, J. Jagieniak, D. Hutzschenreuter, and G. Söylev-Öktem. The fundamental architecture of the DCC. *Measurement: Sensors,* 18:100354, 2021. DOI:https://doi.org/10.1016/j.measen.2021.100354.

[4] Gu, J., Liu, C., Zhuang, Y., Du, X., Zhuang, F., Ying, H., …& Guizani, M. (2020). Dynamic measurement and data calibration for aerial mobile IoT. *IEEE Internet of Things Journal, 7(6),* pp. 5210-5219. DOI:https://doi.org/10.1109/JIOT.2020.2977910

[5] Nummiluikki, J., Saxholm, S., Kärkkäinen, A., & Koskinen, S. (2023). Digital Calibration Certificate in an industrial application. *Acta IMEKO*, *12*(1), pp. 1-6. DOI: 10.21014/actaimeko.v12i1.1402.

[6] Rajan, R. A. P. (2018, December). Serverless architecture-a revolution in cloud computing. In *2018 Tenth International Conference on Advanced Computing (ICoAC),* pp. 88-93. IEEE. 23 December 2019. DOI:https://doi.org/10.1109/ICoAC44903.2018.8939081

[7] Yang, Li & Shami, Abdallah. (2022). IoT Data Analytics in Dynamic Environments: From An Automated Machine Learning Perspective. 10.48550/arXiv.2209.08018. 105 p. DOI:10.48550/arXiv.2209.08018

[8] Mukherjee, S. (2019). Benefits of AWS in modern cloud. *arXiv preprint arXiv:1903.03219*. DOI: https://doi.org/10.48550/arXiv.1903.03219

[9] Wittig, A., & Wittig, M. (2023). *Amazon Web Services in Action: An in-depth guide to AWS*. Simon and Schuster. ISBN: 163343916X

[10] Aquino, G., Queiroz, R., Merrett, G., & Al-Hashimi, B. (2019). The circuit breaker pattern targeted to future iot applications. In *Service-Oriented Computing: 17th International Conference, ICSOC 2019, Toulouse, France, October 28–31, 2019, Proceedings 17,* pp. 390-396. Springer International Publishing. DOI:https://doi.org/10.1007/978-3-030-33702-5_30

[11] H.M. Khan, A. Khan, F. Jabeen, A. Anjum, G. Jeon (2021). Fog-enabled secure multiparty computation-based aggregation scheme in smart grid. *Computers & Electrical Engineering, Vol. 94,* 107358. DOI:https://doi.org/10.1016/j.compeleceng.2021.107358.

[12] Song, B., Yu, Y., Zhou, Y., Wang, Z., & Du, S. (2018). Host load prediction with long short-term memory in cloud computing. *The Journal of Supercomputing*, *74*, pp. 6554-6568. DOI: https://doi.org/10.1007/s11227-017-2044-4

[13] Le, D. M., Dang, D. H., & Nguyen, V. H. (2018). On domain driven design using annotation-based domain specific language. *Computer Languages, Systems & Structures*, *54*, pp. 199-235. DOI:https://doi.org/10.1016/j.cl.2018.05.001