

Tiny oneM2M C Language API

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ABSTRACT

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1. Introduction

The Internet of Things (IoT) has experienced tremendous growth in recent years, with an ever-increasing number of devices being connected and integrated into various applications, such as smart cities, industrial automation, and environmental monitoring. One key aspect enabling this widespread adoption is Machine Type Communication (MTC), which facilitates seamless communication between machines and devices without human intervention. MTC allows for efficient data exchange among heterogeneous devices, leading to better coordination and improved overall system performance.

In this context, interoperability plays a vital role in ensuring the seamless functioning of IoT ecosystems. As the number and diversity of connected devices continue to grow, so does the need for a robust mechanism to manage communication between devices employing different communication protocols, data formats, and standards. MTC gateways serve as an essential bridge between these devices and the network infrastructure, enabling effective data routing and ensuring smooth communication among heterogeneous devices.

Existing MTC gateway implementations predominantly rely on high-level programming languages, which offer the advantages of rapid development cycles and ease of use. However, these high-level languages often come with trade-offs, such as limited control over hardware resources, increased memory overhead, and suboptimal performance. These limitations can pose significant challenges when deploying large-scale IoT systems, where efficient resource utilization, interoperability, and high-throughput data transmission are essential.

In this paper, we present a novel MTC gateway implementation using a low-level programming language to address the limitations of high-level language-based implementations. Our approach is designed to deliver superior performance, reduced memory overhead, and increased control over hardware resources, while maintaining compatibility with a wide range of MTC protocols. By focusing on key challenges associated with MTC gateways, such as protocol interoperability, scalability, and latency, our implementation

aims to provide a robust and efficient solution for the evolving IoT landscape.


Paper structure The remainder of this paper is organized as follows: Section 2 provides a comprehensive review of the related work in MTC gateway implementations, discussing various programming languages and architectural choices, as well as the importance of interoperability in IoT systems. Section 3 delves into the specific challenges associated with MTC protocol integration and outlines the design principles of our novel low-level language-based gateway. Section 4 presents the experimental setup and performance evaluation of our proposed solution. Finally, Section 5 concludes the paper and highlights potential future research directions.

2. Related work

Machine-Type Communication (MTC) has become an increasingly critical aspect of modern communication systems, driving the transformation of various applications in the ever-evolving Internet of Things (IoT) ecosystem. MTC enables the seamless interaction between a vast array of devices, ranging from wearables and smartphones to industrial equipment and smart home appliances, facilitating the data exchange required for intelligent and automated decision-making processes. With the exponential growth of IoT devices and their stringent requirements for low latency, high reliability, and energy efficiency, the implementation of MTC in low-level languages has emerged as a promising solution to address these challenges.

In this section, we will provide an overview of the current state-of-the-art in MTC gateway implementations, highlighting the advantages and disadvantages of various programming languages and architectural choices. Additionally, we will explore the specific challenges associated with MTC protocol integration and discuss how our novel approach addresses these issues to provide a comprehensive solution for the next generation of IoT deployments.

Rubi et al. [1] propose an IoMT platform with a cloud-based electronic health system that collects data from various sources and relays it through gateways or fog servers. The platform enables data management, visualization of electronic records, and knowledge extraction through big data processing, machine learning, and online analytics processing. Additionally, it offers data sharing services for third-party applications, improving healthcare services and inter-

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operability.

The authors in [2] conducted IoTDM service testing for smart city management, focusing on the ecological situation in Saint-Petersburg's central district, using an SDN network infrastructure. They developed a hierarchical model and IoT traffic generator in compliance with oneM2M specifications and implemented HTTP, CoAP, and MQTT protocols. Their findings suggested that HTTP is the most suitable protocol for registering IoT devices to the IoTDM service, while MQTT is optimal for transmitting sensor data. The authors concluded that the SDN approach significantly reduces the RTT parameter, demonstrating its potential in managing IoT traffic in smart city environments.

Soumya et al. [3] explore Fog Computing as a consumer-centric IoT service deployment platform, particularly for connected vehicles and intelligent transportation systems requiring low latency, high mobility, real-time data analytics, and wide geographic coverage. They present an IoT architecture for connected vehicles, integrating Fog Computing platforms into oneM2M standard architecture. The architecture comprises virtual sensing zones, Access Points (RSUs), M2M gateways, and cloud systems. Fog Computing enables consumer-centric services such as M2M data analytics with semantics, discovery of IoT services, and management of connected vehicles. The paper highlights the advantages of Fog Computing, including reduced latency, improved QoS, real-time data analysis, and actuation for superior user experience and consumer-centric IoT products.

This paper [4] presents a cluster-based congestion-mitigating access scheme (CCAS) that addresses the issue of collision and access efficiency in machine-to-machine (M2M) communications. The authors propose a modified spectral clustering algorithm to form clusters based on the location and service requirements of machine-type communication devices (MTCDs), ensuring that devices with similar requirements are grouped together. They also develop an MTCG (machine-type communication gateway) selection algorithm that considers the delay requirements of MTCDs and selects an MTCG with the appropriate forwarding threshold. The proposed CCAS divides the data transmission process into an MTCD-MTCG stage and an MTCG-BS (base station) stage to reduce collision probability and increase the number of successfully received packets, without causing additional average access delays for MTCDs. The paper includes a theoretical analysis of the MTCG aggregation and forwarding process, as well as performance evaluations through simulations.

3. Architecture

4. Proposed Solution

5. Tests

In the following section we present a series of test cases to evaluate the proposed solution's performance, compatibility, and efficiency. These tests cover various aspects, including the impact of different handling methods for the "expira-

Table 1

Hardware, Operating System, Compiler, and Library Specifications for Test Bed Machines.

Machine1	
Hardware	
Model Name	MacBook Pro
Model Identifier	MacBookPro18,1
Chip	Apple M1 Pro
Total Number of Cores	10 (8 performance and 2 efficiency)
RAM Memory	16 GB
Operating System	
Product Name	macOS
Product Version	12.6
Build Version	21G115
Compiler	
GCC Version	Apple clang version 14.0.0 (clang-1400.0.29.102)
Libraries	
SQLite3 Version	3.41.1
cJSON Version	1.7.15

tion time" field in database queries, a comparison of our solution with OpenMTC, cross-platform evaluations on Ubuntu and macOS systems, and compatibility with minimal hardware configurations like the ESP32. By conducting these tests, we aim to provide a comprehensive assessment of the proposed solution's strengths and limitations, allowing for further optimization and refinement to better address the needs of a wide range of applications and use cases.

The Table 1 presents the detailed hardware, operating system, compiler, and library configurations for the machines used for tests. This information is essential for understanding and recreating the testing environment, as well as providing context to the results obtained from the diverse test cases conducted.

In order to thoroughly evaluate the effectiveness and applicability of our proposed solution, it is crucial to conduct a comprehensive set of test cases. First, we aim to evaluate the impact of implementing expiration time field conditions in database queries, focusing on the objective of deleting resources or rendering them unused after the expiration. By comparing the performance of three different scenarios in terms of query time—using the original codebase, the codebase with "expiration time" field as a condition in database queries, and the codebase with "expiration time" field as a condition in database queries when it is indexed—we can assess the time cost of each approach and determine which is most effective. Second, a comparative analysis of latency for 500 AE resource CRUD operations using the proposed solution and OpenMTC will enable us to gauge the relative efficiency of our approach, highlighting its strengths and areas for improvement. Third, performing a cross-platform evaluation through installation and compilation on Ubuntu and macOS systems ensures that our solution is versatile and can be seamlessly integrated into different operating environments. Finally, testing the compatibility of our solution with minimal hardware, such as the ESP32 case study, will help verify its suitability for resource-constrained scenarios,

broadening its potential applications and enabling its adoption in a wider range of use cases.

5.1. Assessing the Efficiency of Meeting Expiration Time Field Objectives in Database Queries on Performance

In this section, we concentrate on a specific test case that evaluates the efficiency of meeting expiration time field objectives in database queries on performance, using codebase version 1.0. The "expiration time" field's purpose is to ensure that resources are deleted or become unused after their expiration. Three distinct approaches were considered, with the first one being the primary focus of this study:

- **Selective Query Filtering** - This approach filters out expired records by adding a condition to consultation, update, and removal queries to apply only to records with a valid "expiration time" field. A REST route is created to delete invalid records. This method is advantageous because it minimizes the overhead associated with constantly checking and deleting expired records while still maintaining data integrity. The performance of this approach will be compared with two other scenarios in terms of query time.
- **On-demand Record Deletion** - In this approach, all requests use the current context to search for records whose "expiration time" field has already passed and, if so, deletes them. This method adds complexity to each request, potentially impacting performance and increasing the likelihood of implementation errors.
- **Periodic Expiration Check** - A thread is created that remains active indefinitely, checking every X time if there are fields with an exceeded "expiration time". However, there is a chance that expired records would still be present when queries are made on the main threads. This approach can lead to additional resource consumption and potential race conditions, making it less ideal than the first approach.

The test case under examination focuses on the first approach, "Selective Query Filtering," and examines its performance in three different scenarios using codebase version 1.0: the codebase with the "expiration time" field as a condition in database queries, the codebase with the "expiration time" field as a condition in database queries when it is indexed in the database, and the original codebase without the "expiration time" field as a condition. The test will be performed by executing 500 SELECT queries in each of the three scenarios on "Machine 1," as shown in Table 1. By evaluating the efficiency of these scenarios in meeting the objectives of the "expiration time" field, we can identify the most effective method for ensuring proper resource management.

The first approach, "Selective Query Filtering," has been chosen as the primary focus of this study due to its potential for minimizing overhead while maintaining data integrity.

The comparative analysis of the three scenarios will provide valuable insights into the impact of different handling techniques for the "expiration time" field on system performance using codebase version 1.0. This assessment will help identify potential optimizations and guide the selection of the most suitable approach for managing resources with an expiration time, ultimately enhancing the overall efficiency of the system.

5.2. Comparative Analysis of Latency for CRUD Operations Using the Proposed Solution and OpenMTC

In this section, we delve into a detailed test case that focuses on the comparative analysis of latency for CRUD (Create, Read, Update, and Delete) operations using the proposed solution and OpenMTC. The objective of this test case is to evaluate the performance of our solution in managing resources against the established OpenMTC standard, providing a benchmark for assessing the efficiency and effectiveness of our approach.

The CRUD operations will be performed through REST requests over the network, rather than on a local machine, as the primary goal of the oneM2M gateway is to facilitate the exchange of information across a distributed network infrastructure. This setup simulates real-world conditions where gateway systems must efficiently handle remote requests, thereby providing a more accurate representation of the solution's performance in practical applications.

By comparing the latency for 500 Application Entity (AE) resource CRUD operations on both platforms, we can highlight the strengths and areas for improvement of our proposed solution. This analysis will not only help us to understand the impact of our solution on system performance but also to identify any potential bottlenecks and areas that could benefit from optimization, particularly in the context of network latency and resource management.

The insights gained from this test case will be crucial in the ongoing development and refinement of our solution, ultimately contributing to a more robust and efficient system for managing resources in the context of the oneM2M standard while accounting for the network-related challenges inherent in distributed systems.

5.3. Cross-Platform Evaluation: Installation and Compilation on Ubuntu and macOS Systems

In this section, we introduce a test case aimed at evaluating the cross-platform compatibility of our proposed solution through installation and compilation on two widely-used operating systems, Ubuntu and macOS. The objective of this test case is to ensure that our solution can be seamlessly integrated into a variety of operating environments, thereby demonstrating its versatility and adaptability to different system configurations.

A cross-platform evaluation is crucial in the realm of computer science, as it verifies the portability and interoperability of software across different platforms. By validating our solution's compatibility with both Ubuntu and macOS,

we demonstrate its ability to function effectively in diverse contexts, catering to a broader range of users and potential applications.

This test case will involve the installation of necessary dependencies, compilation of the source code, and execution of the proposed solution on both operating systems. The evaluation will not only focus on the successful completion of these tasks but also on identifying any platform-specific issues, discrepancies, or bottlenecks that may arise during the process.

The insights gained from this cross-platform evaluation will contribute to the ongoing refinement of our solution, ensuring that it remains robust and effective across various operating environments. This, in turn, enhances its potential for widespread adoption and application in the context of the oneM2M standard.

5.4. Minimal Hardware Compatibility Testing: ESP32 Case Study

In this section, we present a test case focused on assessing the compatibility of our proposed solution with minimal hardware, specifically using the ESP32 microcontroller as a case study. The objective of this test case is to verify the suitability of our solution for resource-constrained environments, thereby broadening its potential applications and enabling its adoption in a wider range of use cases.

Minimal hardware compatibility is an essential aspect of computer science, as many real-world applications require efficient and lightweight solutions that can run on devices with limited processing power, memory, and energy resources. By evaluating the performance of our proposed solution on the ESP32, a popular and cost-effective microcontroller with integrated Wi-Fi and Bluetooth capabilities, we can demonstrate its ability to function effectively under such constraints.

This test case will involve the adaptation, deployment, and execution of our solution on the ESP32 platform. The evaluation will not only focus on the successful completion of these tasks but also on identifying any hardware-specific issues, discrepancies, or bottlenecks that may arise during the process. Additionally, we will assess the resource usage, including memory and processing overhead, to ensure that the solution remains viable and efficient in resource-constrained scenarios.

The insights gained from this minimal hardware compatibility testing will contribute to the ongoing refinement of our solution, ensuring that it remains both robust and versatile, capable of meeting the demands of a diverse range of applications in the context of the oneM2M standard.

Avaliação do impacto resultante do cumprimento do objetivo do campo expiration time

Quanto tempo demora a GET/POST/PUT/DELETE 500 AEs usando a nossa solução e a solução disponível do Open-MTC na mesma máquina (na máquina do MEI-CM) na rede - Saber o tempo de cada um dos 500 e calcular, mínimo, máximo, média, desvio padrão

Instalação e Compilação em máquinas Ubuntu e MacOS (verificar se corre em outros SOs)

? Fazer testes com Hardware mínimo - por exemplo ESP32 ?

CRedit authorship contribution statement

: Conceptualization of this study, Methodology, Software.

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My name is Rafael Pereira, I'm 22 years old, and I'm an MSc Computer Engineering Student and Researcher at Polytechnic of Leiria. I'm extremely curious about the technology world, ambitious for knowledge in this area, I'm dedicated to doing my work. The programming thing always got me, and every day it grows. Today I'm looking for interesting projects, that can make me think and learn every day.