

Introduction

The theme of World Metrology Day in 2022 was “Metrology in the Digital Era”, which implies that metrology is entering the digital age. The 27th CGPM adopted the Resolution 2, suggesting a digital metrology system based on the SI Digital Framework^[1]. BIPM has centered on Digital Quality Infrastructure, highlighting the significance of machine-readable, machine-executable, and machine-interpretable metrological digital certificates for global measurement value unification and mutual recognition^[2].

To promote metrological digital certificate adoption and drive metrology process digitalization, a metrological digital certificate system supporting fully digital services is essential. Yet, this system faces many challenges:

- ① Solutions that are continuously iterated and updated due to the rapid development of digital technology;
- ② Changes such as the version of the meta-model caused by the changes in management criteria and the expansion of certificate types;
- ③ The system requires collaboration and interaction among multiple parties.

In order to address these challenges, the architectural design of the metrological digital certificate system is particularly crucial. The architectural design of the system needs to follow the following principles:

- ① System design with high cohesion and low coupling;
- ② The requirements of metrology digital data in line with FAIR+T(Traceability);
- ③ Clear, standardized, and transparently public interface design;
- ④ Base on the SI Digital Framework.

All metrological terms, quantities, units, etc. involved in the system must be traceable to the SI Core such as SI Reference Point. As such, the design of the architecture of system and the service layer assumes crucial significance.

System implementation

The system uses the Spring Cloud framework. Service modules are in Java and Python. The interface layer API Gateway is Spring Cloud Gateway. The NIM - DCC website^[5-6] is developed for DCC related instructions.

Digital security service offers an RFC3161 timestamp interface recognized globally. For CA, a dedicated RA helps with info review.

The implementation of the application layer relies on the interfaces offered by the service layer. By providing services in the form of RESTful APIs, the implementation of the application layer becomes more flexible. Moreover, it can separately furnish data interfaces for both human users and machines.

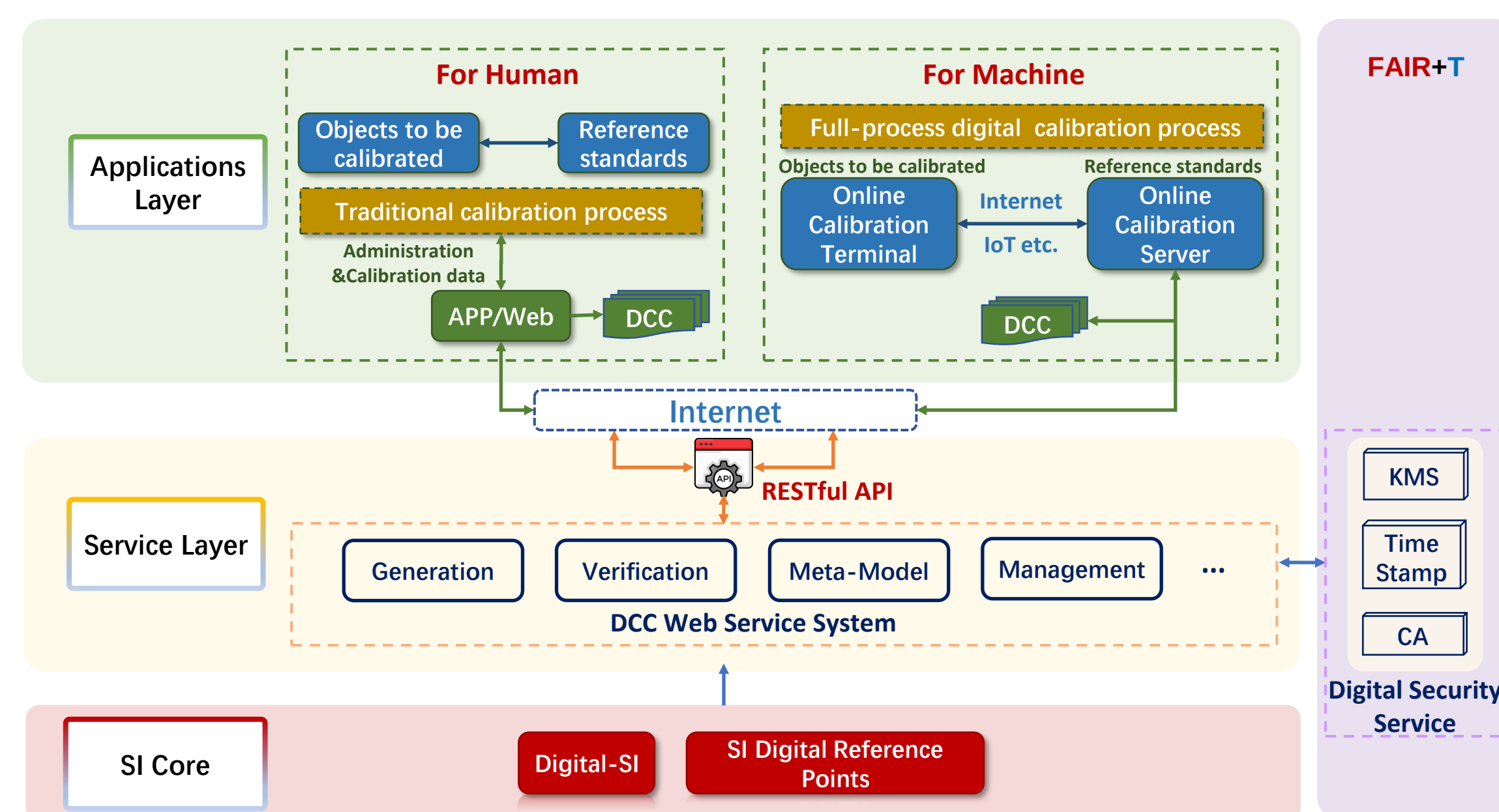


Figure 3. The system provides interfaces for both humans and machines to the applications layer.

System architecture

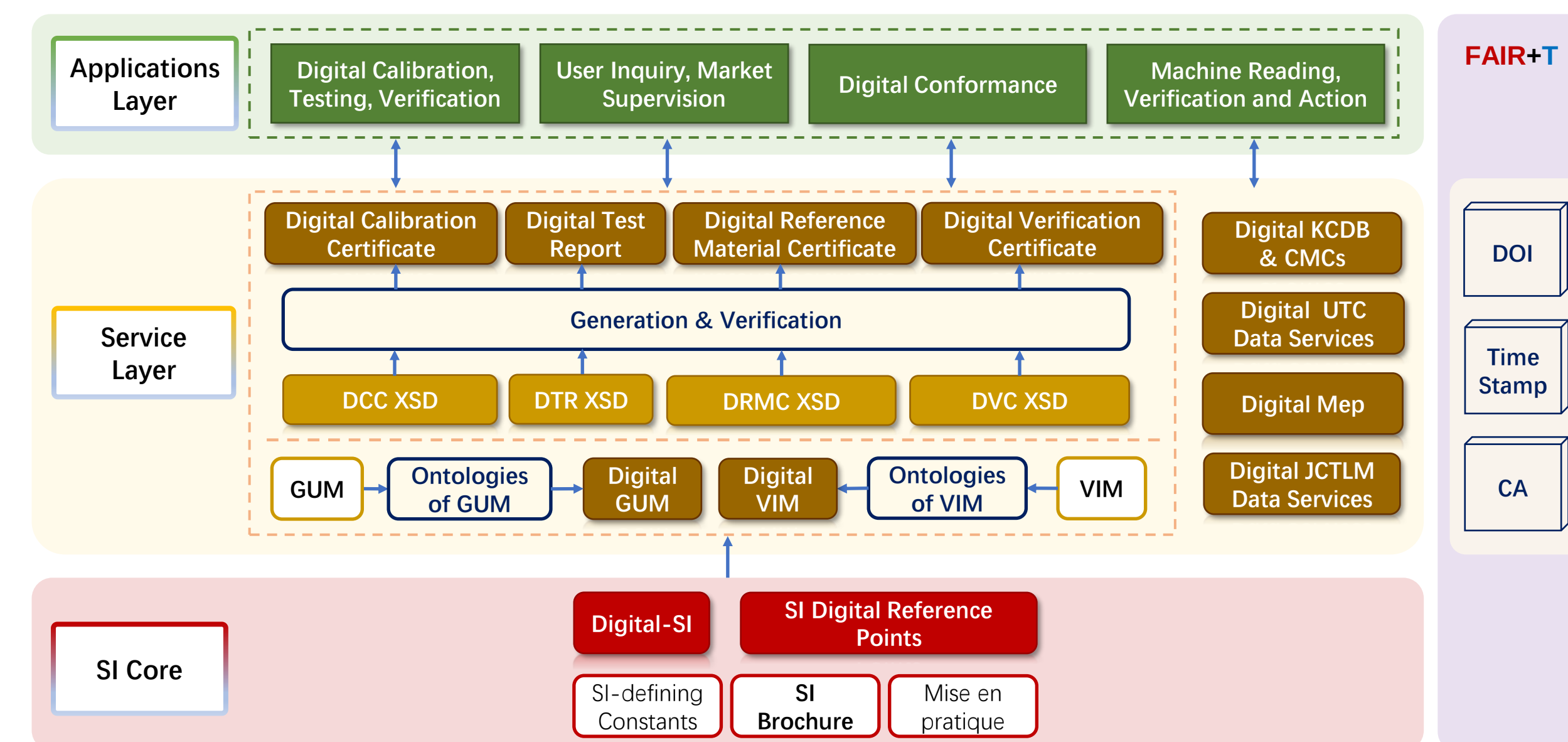


Figure 1. Architecture diagram of the metrological digital certificate system based on the SDF

The system has three layers^[3]: the SI core layer, service layer, and application layer. It also incorporates relevant security services.

- ① The SI core: SI Reference Points; Digital - SI.
- ② The service layer is divided into three categories:
 - Digital metrological terminology services: D-VIM, D-GUM (digital ontologies for VIM, GUM, meta-models and verification tools, etc.).
 - Digital services for metrological data (KCDB, UTC, JCTLM Data Services), reference data sets and test data sets.
 - Digital certificate services: DCC, DTR, DVC, DRMC, etc., including the meta-model and relevant generation and verification services.
- ③ The application layer: the application of metrological digital certificates.
- ④ Digital security: complies with FAIR+T rules, includes DOI, digital signature, and timestamp service systems.

Service layer architecture

For the service layer architecture, taking DCC as an example, the DCC system mainly comprises the DCC network service and digital security systems.^[4]

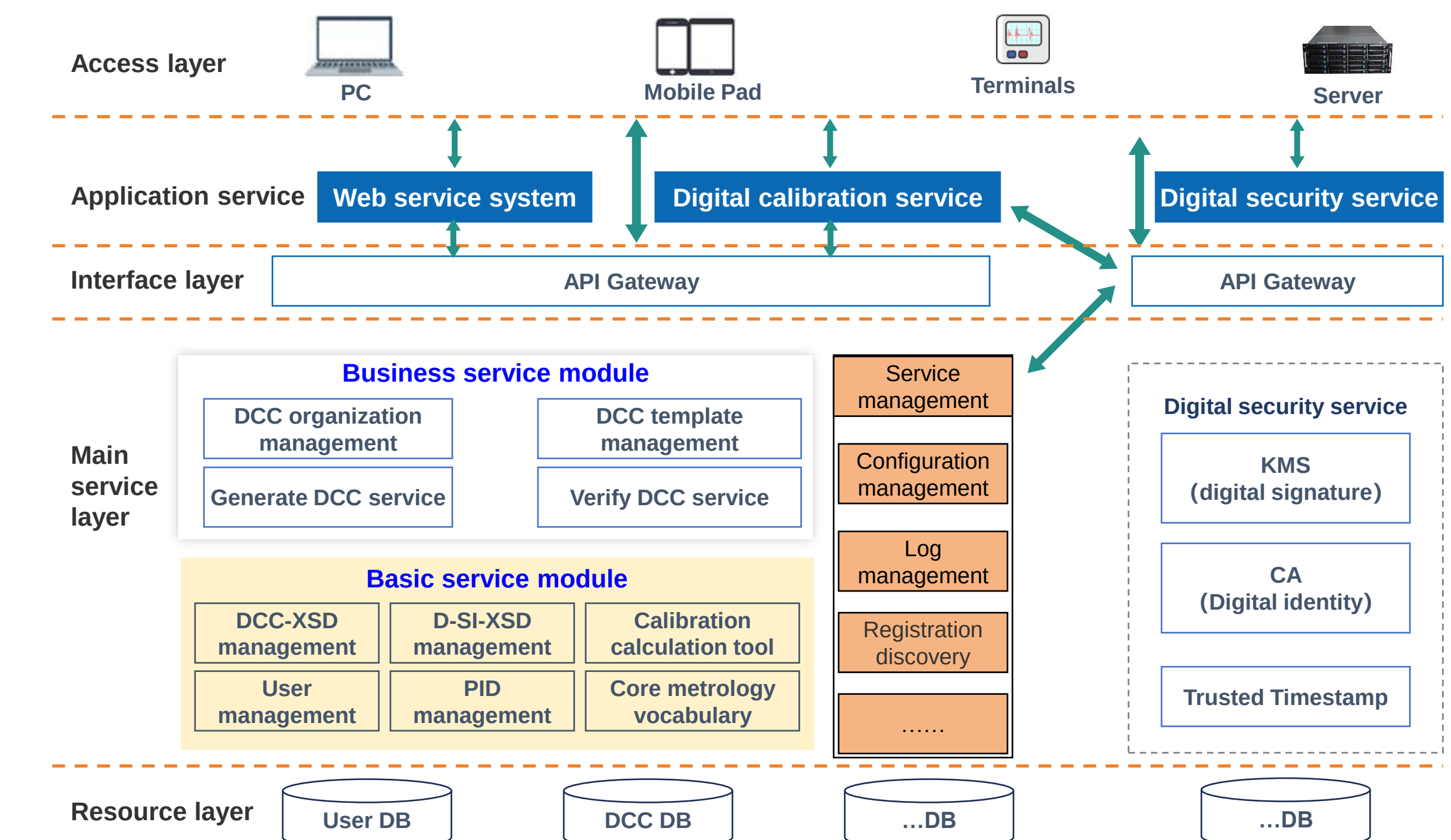


Figure 2. Architecture of the Digital Calibration Certificate System Based on Microservices

- ① Access layer: Users can access the system through multiple terminals. They can communicate with the Application layer or directly with the Interface layer;
- ② Application layer: It provides web services for humans and machines respectively;
- ③ Interface layer: It provides service interfaces of business compliance modules and basic service modules for both the Access layer and the Application layer;
- ④ Main service layer: It is the main service layer of the DCC, including the business service module, the basic service module, and the service management module;
- ⑤ Resource layer: The relevant databases for DCC services.

Application and validation

Currently, functions like auto- generation, verification, and management of digital certificates are realized in multiple fields. For humans, digital certificates can be generated and verified in a website wizard application. For machines, full-process digital calibration in the time& frequency field is achieved.

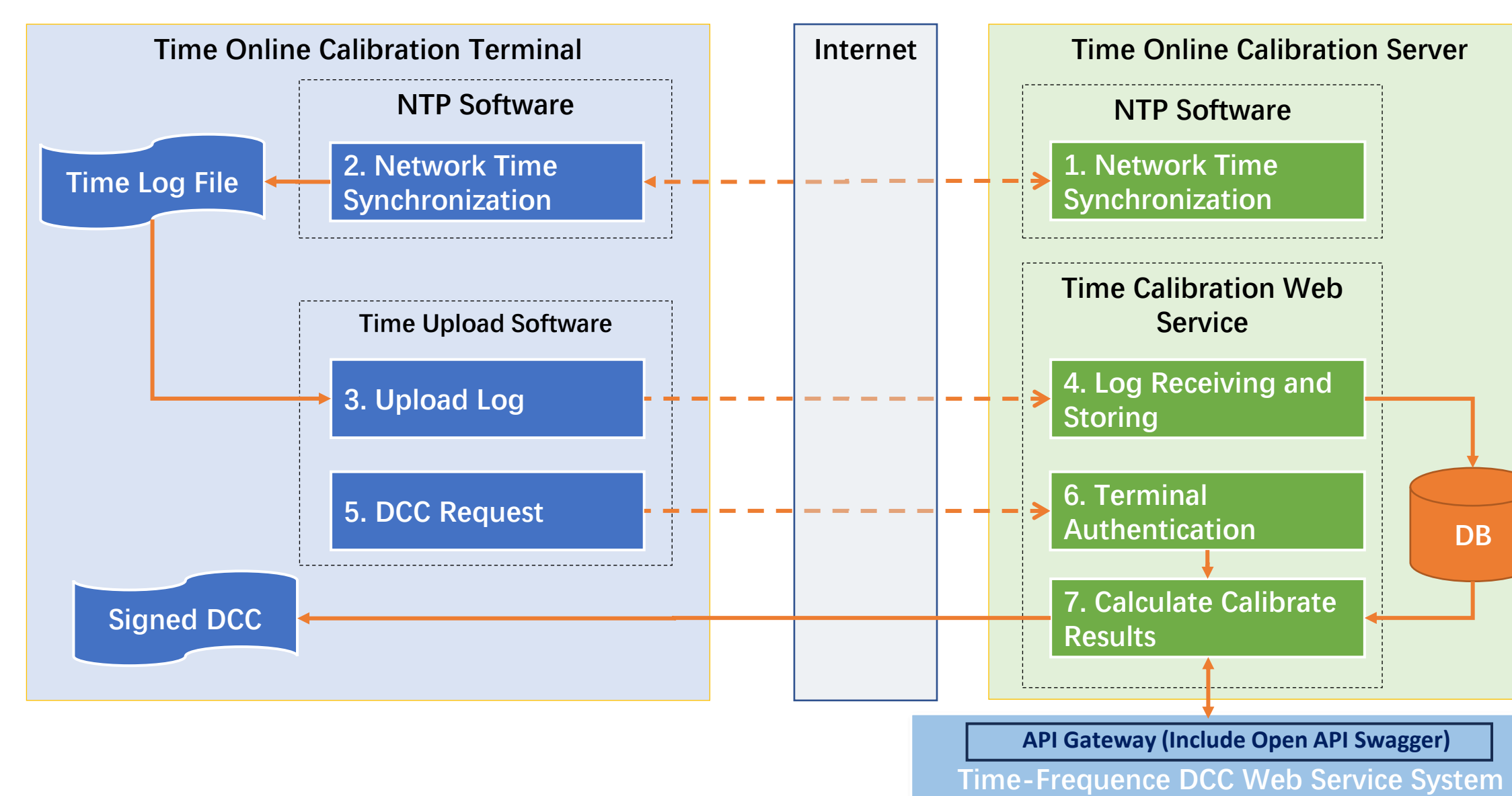


Figure 4. Schematic diagram of the full-process digital calibration process in the Time & Frequency field

The full-process digital calibration in the field of time and frequency is based on the NTP protocol. Data flows between the remote terminal and the calibration server via the internet. See Figure 4 for details. Meanwhile, through the services provided by the system, multiple applications of DCCs has been realized, such as the implementation of using RFID tags as the carrier of DCC^[7], etc.

Conclusion-Future

The metrological digital certificate system based on the SI Digital Framework and microservice architecture has been successfully developed. It encapsulates service functions like certificate generation, verification, and management. In the time - frequency field, it has achieved full - process digital calibration, validating the architecture's practicality and adaptability. Now, efforts are being made to extend full - process digital calibration to areas like vibration, gears, and charging piles.

This architecture supports future integration of AI, LLM, or AI Agent for subsystem intelligence. It will also promote international cooperation and standardization to build a more secure, open metrological digital ecosystem, accelerating global metrology digital transformation.

References

- [1] BIPM, Resolution 2 of the 27th CGPM (2022), 2022. Online [accessed 17 February 2025] <https://www.bipm.org/en/cgpm-2022/resolution-2>
- [2] CIPM, 1st meeting of the FORUM-MD, 2024. Online [accessed 17 February 2025] <https://www.bipm.org/en/committees/fo/forum-md/1-2024>
- [3] Xiong, X.; Zhu, Y.; Li, J.; Duan, Y.; Fang, X. A digital framework for metrological information. Meas. Sens. 2021, 18, 100122. <https://doi.org/10.1016/j.measen.2021.100122>
- [4] Xiong, X.; Liu, Z.; Kan, K.; Zhu, Y.; Zhang, W.; Fang, X. Design and implementation of a digital calibration certificate web service system based on microservice architecture. Meas. Sens., 2024, 101487. <https://doi.org/10.1016/j.measen.2024.101487>
- [5] NIM, DCC Base API, 2023. Online [accessed 17 February 2025] <https://dcc.nimdc.ac.cn/dcc-doc/v1/dcc-base/swagger-ui/index.html#/>
- [6] NIM, DCC Wiki, 2023. Online [accessed 17 February 2025] <https://www.nim.ac.cn/dcc/>
- [7] Kan, K.; Wang, S.; Liu, Z.; Xiong, X. Design and Implementation of Digital Calibration Certificate for RFID Tag Storage. Sensors 2024, 24, 6626. <https://doi.org/10.3390/s24206626>