MEC and IoT Based Automatic Agent Reconfiguration in Industry 4.0

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***Abstract*—The Internet of Things (IoT) and connected devices are impacting enterprises, public sector bodies, and citizens in many ways. In parallel, upcoming 5G and Multi-Access Edge Computing (MEC) are aiming to enable ultra low latency use cases for IoT. This paper proposes to utilize MEC and IoT based architecture for automatic agent reconfiguration in smart manufacturing floors. The EURECOM IoT Platform is extended to achieve this purpose.**

***Keywords*-Agent Reconfiguration; Edge Computing; Industry 4.0; Internet of Things.**

I. Introduction

The recent growth in connected devices and applications leveraging the IoT has contributed to a steep rise in data processing and intelligence generation demands. Cloud Computing provides a suitable infrastructure for this. But massive and critical IoT use cases have demonstrated the need of having distributed intelligence across the entire IoT architecture elements rather than centralized intelligence in the Cloud. This brings the attention to Multi-Access Edge Computing (MEC) [1] platforms. Such platforms are critical for Smart Manufacturing or Industry 4.0. It is anticipated to bring significant service & maintenance cost savings through predictive maintenance, reduce time to manufacture through Digital Twin concept [2], and promote circular economy. The realization of a smart manufacturing facility involves monitoring, control, configuration of the IoT devices, robotic agents automatically. But many industries are facing challenges with automatic reconfiguration of agents after they have finished their assigned tasks. This paper addresses this particular challenge utilizing MEC and EURECOM IoT Platform[1].

Rest of the paper is organized as follows. Section II reports the evolution of the IoT Platform from a monolithic architecture to a microservice based end-to-end architecture. This section briefly presents the current state in Industry 4.0 research directions. Section III dives into the automatic agent reconfiguration. The mentioned IoT Platform is extended for this purpose. The configuration message structure and the newly developed APIs are described along with operational steps. Section IV concludes the paper.

II. State-of-the-art

This section reports the evolution of EURECOM IoT Platform as well as the current state of research on Industry 4.0.

[1] https://iotplatform.eurecom.fr

A. Evolution of IoT Platform

Our first IoT architecture was monolithic and an IoT gateway centric [3], [4]. IoT devices and client applications were directly interacting with the gateway over Machine-to-Machine (M2M) area networks (e.g. Bluetooth Low Energy, Wi-Fi). The devices and applications exchanged data using a unified data model based on JSON schema. The application logic and web services were centralized in the IoT gateway. This architecture had basic security features including self-signed SSL certificates and AES-256 encryption keys stored in IoT devices for encrypted data exchange. This architecture is described in Fig. 1.

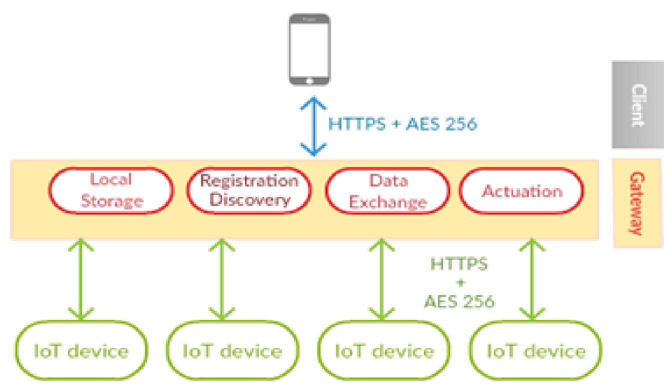

Fig. 1. Monolithic and gateway-centric IoT architecture.

With advancements in research and development, we introduced Cloud and Edge Servers components in our IoT architecture which resulted in Fig. 2. The IoT gateway functionalities were virtualized in the Cloud as IoT common service functions (CSFs) following the oneM2M IoT architecture Standard [5]. The CSFs include web services for device registration, discovery, data access, storage etc. We also adopted the principles of microservice which allows deployed the CSFs as loosely coupled services using Docker. The Edge Server allowed distributing the intelligence closer to the IoT devices. The Edge Server supports features including sensor data validation, metadata annotation, local data processing, and local actuation. Such extensions of the first architecture was necessary to support data-centric IoT services [6] and use cases. The benefit here is to decouple the IoT services from infrastructure dependencies and the intelligence becomes datadriven and distributed between the Cloud and Edge Servers.

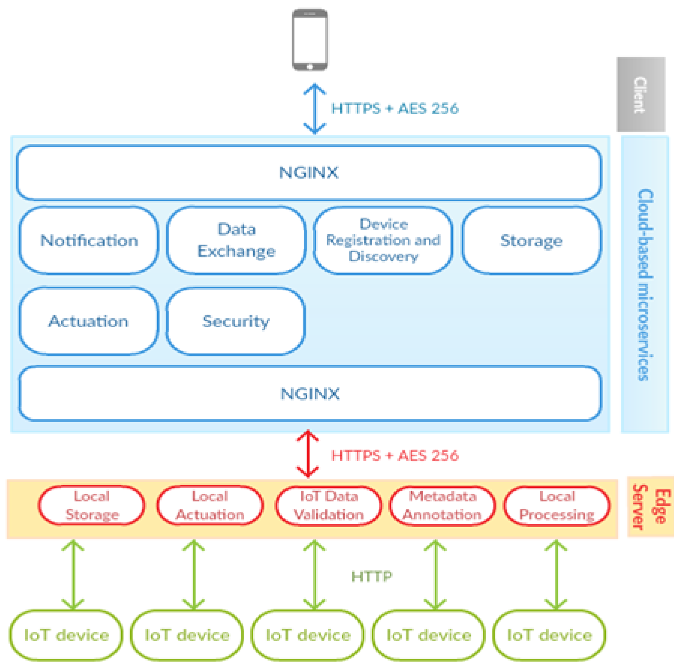

Fig. 2. Data centric IoT architecture.

The third evolution of the IoT architecture led to significant improvements in security features. JSON Web Token (JWT)[2] based authentication and authorization were added. SSL certificate from a trusted vendor is utilized in the Cloud along with AES-256 for data exchange. A total of eight CSFs are implemented in the Cloud. A web browser based dashboard is also introduced along with the mobile application as Human Machine Interfaces (HMIs). Previous architectures supported only HTTP protocol binding but now an MQTT broker is incorporated to support data exchange using MQTT[3] over SSL. The resulting secure and end-to-end IoT Platform is depicted in Fig. 3.

B. Industry 4.0

From a high level perspective, Industry 4.0 is about utilizing the IoT and Cyber Physical Systems (CPS) [7] deliver automation and manufacturing process improvement, lowering production & maintenance costs, increasing reuse, and higher quality throughout the production and distribution cycle. An advance manufacturing solution using Industry 4.0 is presented in [8]. The authors presented an empirical approach to improve the speed of production management and troubleshooting information which has a positive impact on reducing cost of manufacturing. The entire framework is composed of a Cloud Platform, embedded systems, and wireless sensor network.

The author of [9] described the features of Industry 4.0 including smart networking, mobility, flexibility, integration

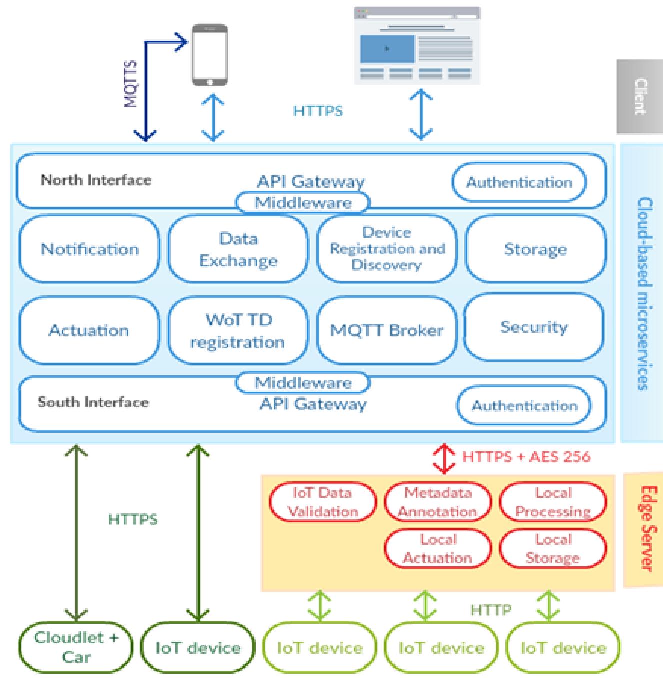

Fig. 3. Secure and end-to-end IoT architecture.

of customers, and business models. The paper also presented a study of compatibility of CPS with Industry 4.0 and a simple prototype. A more in-depth discussion is found in [10]. This paper presents the concept of digitalization in the context of digital factory to intelligent factory. It proposes dynamic configuration mode of production rather than a fixed production line. The authors showed that in an automotive production unit, there is considerable savings of resources.

From the above discussion, it is clear that majority of the research and technology developments in Industry 4.0 is solely focused on CPS aspects and are in its infancy. This paper extends the EURECOM IoT Platform for automatic agent reconfiguration for Industry 4.0. This not only advances the state-of-the-art but also introduces a novel direction in robotic agent configuration performed in smart manufacturing facilities.

III. Automatic Agent Reconfiguration

The technical challenges around automatic agent reconfiguration in a smart manufacturing facility are manifold - (i) lack of a uniform description of the configuration, its serialization technique, (ii) Open API allowing such reconfiguration, (iii) hosting the relevant service in a MEC platform, and (iv) overall IoT architecture enabling the automatic agent reconfiguration. These challenges are addressed in the subsections below.

A. Uniform Description for Agent Configuration

We utilize W3C Web of Things' Thing Description (TD) approach for the uniform description of agent configuration. This approach has many benefits - (i) describing the agent configuration in terms of events, properties, and actions, (ii) utilizing the

[2]https://jwt.io/
[3]http://mqtt.org/

ongoing WoT standards preserving interoperability, (iii) JSON-LD for serialization, and (iv) ease of implementation.

The events signify generic interactions where such robotic agents exchange data with other IoT devices or applications. The properties are data points which can be read (for sensors) or written to (for actuators). So, properties allow the MEC Platforms to gather data from agents as well as control the agents. The actions represent invocable processes and are specific to control features of actuators present in agents (e.g. motors for movement). Such configurations are serialized using JSON-LD[4]. It is a lightweight linked data format, based on the JSON format, and provides a mechanism for JSON data interoperation at the Web scale. Another advantage of using linked data philosophy is that it allows creating a network of standard-based[5], machine-readable data across the IoT Platforms. This in turn eases the operations on the configuration data (e.g. storage, transport) for the EURECOM IoT Platform.

Following parameters (shown in Table I) are used to represent the agent configuration.

TABLE I
UNIFORM DESCRIPTION PARAMETERS FOR AGENT CONFIGURATION

Parameter	Description
Agent name	Describes the agent name
Agent ID	Unique ID of the agent
Job ID	Unique ID of the assigned job
Job name	Describes the assigned job
context	jsonld context file
base URL	Base URL to access the agent
Path	path to access web services exposed by the agent
Interactions	lists the supported events, properties, and actions

B. Open API for Agent Reconfiguration

A new microservice and an API are developed to support the automatic agent reconfiguration. Following is a description of the open API.

- **Purpose.** The new open API is implemented to enable automatic agent reconfiguration. The API is hosted on the MEC Platforms. The agent configuration is set from the Cloud which pushes the configurations to the MEC platforms where the respective agents are connected. When the assigned tasks of the robotic agents are complete, the agents connect to the MEC Platforms to retrieve the reconfiguration files for new job.
- **Base URL.** https://iotplatform.eurecom.fr
- **Path.** /n/agentReconfig (since the API is access through the north interface of the EURECOM IoT Platform.
- **Method.** HTTP POST method is used to send the agent configuration details from a Cloud-based dashboard to the MEC Platforms deployed in the smart manufacturing facilities.
- **HTTP headers used.** The 'x-access-token' header is used to send the JWT obtained during authentication. The JWT is used by the Cloud and MEC Platforms as a means for token based authentication and authorization to access the implemented microservice. In addition to that, 'Content-Type' is set to JSON-LD.
- **Input message structure.** It consists of a message containing the description of Table I in JSON format.
- **Output message.** On successful exchange of agent configuration message, HTTP 200 status code is returned with a message "Agent configuration received".
- **Error message.** In case of an error, one of the following status codes and messages are sent by the MEC Platform - (i) HTTP 403 (forbidden) with a message "You are not authorized to access this web service", (ii) HTTP 404 (Not found) with a message "Path not found", and (iii) HTTP 503 (Server not available) with a message "Server currently unavailable".

[4]https://json-ld.org/

[5]https://www.w3.org/2018/json-ld-wg/

C. Extending EURECOM IoT Platform

To accomplish the uniform description generation, exchange, and storage at the MEC Platforms, the EURECOM IoT Platform's capabilities are extended. This gives rise to an architecture depicted in Fig. 4. To interact with multiple robotic or autonomous agents in a manufacturing floor, more Edge Servers are added. These Edge Servers are basically MEC Platforms capable of performing advance local data processing and aid in agent reconfiguration. Although the Fig. 4 shows only three MEC Platforms connecting nine IoT devices (i.e. agents), additional such subsystems can be added as per requirements.

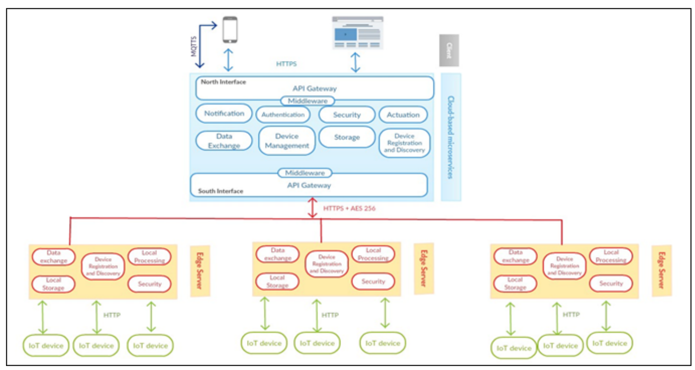

Fig. 4. Extended EURECOM IoT Platform for automatic agent reconfiguration.

The device registration and discovery microservice introduced in the Edge Servers is responsible for storing and managing the agent configurations. Each configuration is valid for a job ID and duration. When the duration is over, the agents (i.e IoT devices shown in Fig. 4) receive new configuration from an Edge Server. The steps for this automatic reconfiguration is shown in the Fig. 5.

At the beginning, the client (accessing the dashboard from a web browser) must authenticate itself to receive a JWT. On successful authentication, the client is then presented with an interface where the uniform configuration description of the agents can be generated. Once completed, the configuration along with the JWT are posted to the Cloud server web service - device registration and discovery. The API gateway shown in Fig. 4 verifies the JWT to determine if the token is valid. On successful verification, the received agent configuration is validated in the Cloud with respect to valid JSON schema and WoT TD based formating. Then the description is stored in the Cloud and communicated to the Edge Servers (i.e. the MEC Platforms) for caching. These servers are directly connected to the autonomous agents. When any agent completes its current task or job, it connects to one of the Edge Servers to retrieve the reconfiguration details for a new job.

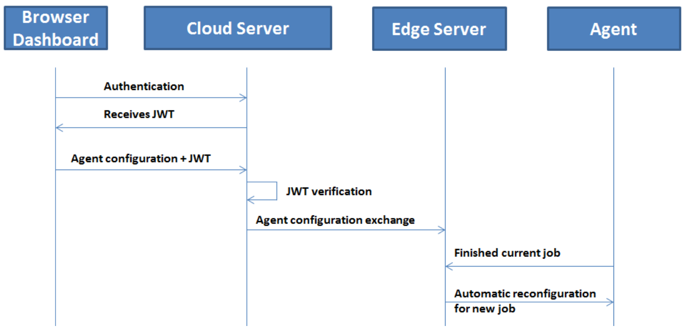

Fig. 5. Operational steps for automatic agent reconfiguration.

The new web service is developed using MEAN stack (MongoDB, Express JS, Angular JS, and Node JS) and deployed as a microservice in a Docker container.

D. Automatic UAV Mission Reconfiguration

Unmanned Aerial Vehicles (UAV) related IoT Platforms are increasingly becoming popular [11]. Such devices are also considered as an automatic agent in Industry 4.0 since UAVs have many applications like manufacturing site inspection. We extend the same philosophy described in the previous section to reconfigure UAVs automatically for a new mission. For this purpose and operating UAVs, the EURECOM IoT Platform shown in Fig. 3 is extended to include three new web services - real time video analytics, mission definition, and telemetry monitoring service. They are shown in Fig. 6.

The mission definition web service is supported by an application which interacts with the clients to receive following information - mission unique ID, mission description, user comment, priority, start time, duration, tasks, status, creator, and supervisor. These information are received in the EURECOM IoT Platform and following a mission, are sent to the UAV to automatically reconfigure it for a new mission. In this case, the UAVs are considered as MEC Platforms.

IV. Conclusion

In a nutshell, the paper describes the benefits of Industry 4.0 for manufacturing enterprises. With increased automation in manufacturing floors, reconfiguration of robotic agents can be automated through MEC Platforms and IoT. We described an extension to the EURECOM IoT Platform for automatic agent reconfiguration along with the open API and operational

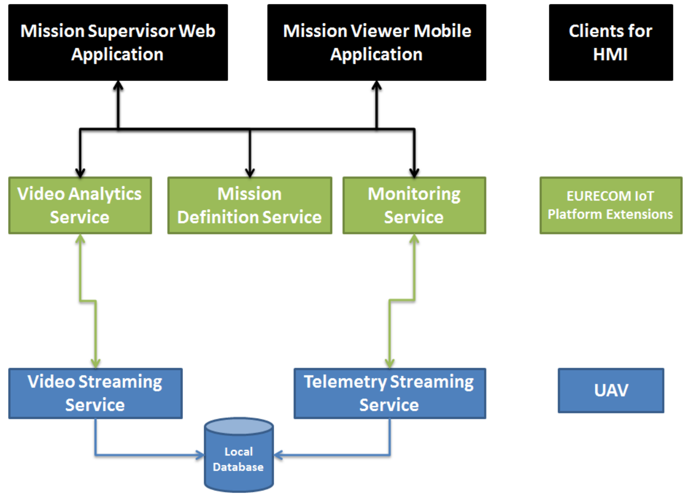

Fig. 6. Web services for automatic UAV mission reconfiguration.

steps. The presented framework solves an important technical challenge for the manufacturing enterprises looking into increasing productivity. For future work, we are going to deploy the system in a real setting for performance evaluation.

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