Cloud to Sensors Field Level Connectivity

Architecture

Introduction

As it was explained in Sect 1, to follow the Industry 4.0 concept a hybrid environment integrating reactive Machine to Machine interconnection and interactive web-based user interface is required. The main challenge of the solution in concern is to design a generic but reusable architecture that addresses interoperability of these diverse interconnection scenarios ruled by different requirements, namely

1. **machine-centric** machine to machine real-time mobile interoperability
2. **human-centric** cloud-based front-end

Interconnection of the reactive **machine-centric** and interactive **human-centric** environments can be implemented by applying one of the following scenarios:

- **direct interconnection** - cloud-based dedicated communication services are engaged to attach it to the cyber-physical system making up a consistent M2M communication network using a common protocol stack
- **gateway based interconnection** - native build-in communication services allows attaching the cloud to the cyber-physical system using an out-of-bound protocol stack

In the solution in concern, the interconnection of assets is not enough hence their interoperability is expected. In this case, using the same communication stack must be recognized as only a necessary condition. To support interoperability common data understanding is required. By design, the direct approach requires that the cloud has to be compliant with the interoperability standard the cyber-physical system uses. As a result, it becomes a consistent part of the cyber-physical system. Additionally, to meet this requirement the cloud and cyber-physical systems have to establish

- directly the same semantic-context
- directly the same security-context

The possibility to establish a common semantic-context in the multi-vendor environment makes communication standardization especially important. In this case, it is required that the encoding of the payload of messages exchanged over the network (Data Transfer Object - TDO) is standardized so that the payload can be factored on the data-gathering site and consumed on the ultimate destination data processing sites. Security between the data origin and ultimate data destination refers to the protection of messages (security-context) against malicious users. It is required that communicating parties are using the same cyber-security measures.

why not direct

The decision to follow the **direct interconnection** scenario must be derived from an analysis of the capabilities of available services in concern. However, for the development strategy of this type of solutions this analysis can be done partially taking into account two features that can be considered invariable:

- by design the cloud-based services must be virtual - they are used to handle many solutions at the same time
- by design the M2M communication is usually constrained by the real-time requirements

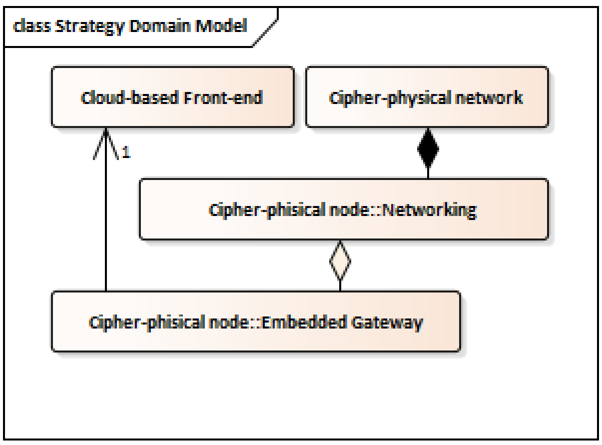
In practice, the set of assets embedded in the cyber-physical system is very stable. On the another hand, the virtualization of services means that they must be very flexible to handle the attachment of new assets proactively (acting in advance) at run time. As a result, by design, the cloud services must be repressible to register and authenticate devices exposing endpoints in the public network to allows the device to access a provisioning cloud service. It requires that a session over the Internet has to be established by the data holding asset at a preparation step.

To meet the requirements of real-time distributed control the cyber-physical system may use protocols applicable only to local computer networks (e.g. multicast IP, Ethernet, TSN, etc.). Because the cloud services support only protocols handling interconnection over the Internet the interaction with the cloud requires remote agents, i.e. agents attached locally to the M2M network implemented applying one of the following archetypes:

- **edge device** - remote cloud agent acting as an intermediary for nodes of the cyber-physical network
- **field level gateway** - a dedicated custom device acting as an intermediary for nodes of the cyber-physical network
- **embedded gateway** - a software part composed into a selected node of the cyber-physical network

Edge device is a device that connects directly to the cloud services but acts as an intermediary for other devices called leaf devices. Additionally, it allows the selection of initial data processing and execution of them using local resources. The **edge device** may be located close to the leaf devices and attached to the cyber-physical network using protocols applicable only to local computer networks. In this scenario, it is possible to use a custom protocol stack to get connected to the **edge device** with the cloud and helps to save the bandwidth thanks to sending only the results of local processing. In this approach, the **edge device** is part of cloud vendor products and cannot be recognized as a generic solution that can be used to connect to other clouds at the same time.

The **field level gateway** is also build atop of the middleware concept. The only difference compared with the **edge device** is necessity to use officially supported by the cloud vendor services to get connected. In this scenario the process data may be transferred to many clouds at the same time provided that the gateway offers this functionality.



Unlike the above described solutions, the **embedded gateway** is not derived from the middleware concept. The domain model for this archetype is presented in the Fig. Promoting separation of concern design principle, the gateway functionality should be implemented as a self-contained software part embedded in the `Networking` service of the `Cipher-physical node`. Main functionality of this component is to transfer selected data between `Cipher-physical network` using `Networking` services of an existing `Cipher-physical node` and `Cloud-based front-end` using officially supported by the cloud vendor interconnection services.

The **embedded gateway** archetype relaxes most of the issues described above: cipher-physical network real-time behavior, data encoding incompatibility, security-context differences to name only a few. The main goal of this article is to provide proof that that the **embedded gateway** archetype implementation is possible based on a generic architecture that can be used as a foundation for the integration of the heterogenous environments in concern. The proposed implementation is designed for selected interoperability standard and cloud product.

Why pubsub

To comply with the Industry 4.0 communication criterion, even the lowest category requires that the product must be addressable over the network via TCP/UDP or IP and has to support the OPC UA Information Model. As a result, any product being advertised as Industry 4.0 enabled must be OPC UA-capable somehow. To support the multi-vendor environment OPC Unified Architecture interoperability standard has been selected. OPC UA supports the following two patterns to be used to transfer data between communicating parties:

- connection-oriented: requires a session that has to be established before any data can be sent between sender and receiver
- connectionless-oriented: the sender may start sending messages (called packets or datagrams) to the destination without any preceding handshake procedure

Using the connection-oriented communication pattern it is difficult or even impossible to gather and process mobile data (Sec. I), which is one of the Internet of Things paradigms. OPC UA Part 14 PubSub offers the connectionless approach as an additional option to session based client-server interoperability and is a consistent part of the OPC UA specifications suit. As the result it can be recognized as the IoT ready technology.

> [29] Mariusz Postol, UA Part 14: PubSub Main Technology Features in Object Oriented Internet, https://github.com/mpostol/OPC-UA-OOI, 2019, DOI: 10.5281/zenodo.1198852

Why Azure

The presented proposals in the article are backed by proof of concept reference implementations. For this study, prototyping addresses Microsoft Azure cloud products. There are many reasons for selecting Azure to accomplish cloud-based front-end of CFS. Azure offers Infrastructure as a Service (IaaS) and Platform as a Service (PaaS) capabilities. As a result, the platform can be used not only as a cloud-based front-end for CFS. By design, the Azure services are compliant with Security Development Lifecycle (SDL) an industry-leading security process. It is also compliant with the new international standard for cloud privacy, namely ISO 27018. Solutions hosted on Azure are scaled up to millions of users without any additional coding. For the development of the CFS front-end, it is essential that Azure provides very efficient storage services usefully for real-time process data archival. Azure provides a vast variety of hybrid connections including but not limited to virtual private networks (VPNs), caches, content delivery networks (CDNs), ExpressRoute, and IoT dedicated services that can be directly used to implement cloud-based front-end for CFS. Because it is also integrated with other Microsoft tools like Office 365, Outlook, and SharePoint using Azure allows preserving investment and exporting process data to the mentioned tools. Azure also offers services supporting analytics and intelligence capabilities for further improving business processes and decision making. It is the only cloud platform that offers Blockchain as a Service (BaaS), Machine Learning, Bots, and Cognitive APIs capabilities.

Azure aids Internet protocols and open standards such as JSON, XML, SOAP, REST, MQTT, AMQP, and HTTP. A software development kits for C#, Java, PHP, and Ruby are available for custom applications. Azure provides services supporting data exchange over the OPC UA, but they don't support pubsub compliant with the OPC UA Part-14. Connectivity services on the network use JSON-based Data Transfer Object encoded based on schema derived from the solution metadata.

More detailed description of the selected Azure features in context of the application in concern are covered by the Sec. `azure-main-technology-features`.

Why OOI

Based on the sessionless and session-oriented communication patterns examination against the IoT requirements (cite mpostol 2020) it could be concluded that the connectionless pattern better suites issues related to the assets mobility and traffic asymmetry that is characteristic for the application domains in concern. Additionally, to promote interoperability and address the demands of the M2M communication in the context of a multi-vendor environment the prototyping should use an framework that must be compliant with the OPC UA Part 14 PubSub spec. According to proposed architecture presented in Fig. above to implement the `Embedded Gateway` as a composable part of the `Cipher-physical Node` a library implementing `Networking` functionality in compliance with mentioned above specification is a starting point for further development. Additionally it must be assumed that the library used to deploy `Embedded Gateway` support dependency injection and be capable to compose an external part supporting Azure/pubsub gateway functionality. The composition process must be available without modification of the core code of an existing library. As a result the prototyping is to be limited to implementation of the `Embedded Gateway` software part only.

A library that meets all these requirements has been implemented consistently with the Object-Oriented Internet paradigm `\footnote{\url{https://github.com/mpostol/OPC-UA-OOI}} \cite{RefWorks:doc:5c66740ae4b081adf5804596}` worked out in an open-source project. The `cite {mpostol 2020}` covers the description of a reference application program implementation proving that it is possible to design universal architecture targeting reactive interoperability as a consistent part of the Object-Oriented Internet concept compliant with the OPC UA PubSub `\cite{RefWorks:doc:5d98837de4b055984c0eecf0}` international standard. According to the presented implementation and evaluation, using the dependency injection and late binding, the application program can be seamlessly adapted to the production environment and scales well. This approach also improves flexibility and adaptability of the existing solutions against any modification of the production environment including but not limited to the selected interoperability standard change.

Sect. `OPC UA PubSub Main Technology Features` provides more detailed description of this library and new functionality (`Embedded Gateway` part deployment process.

The following subsections covers description of the current state of technologies with regards to OPC UA pubsub and Azure cloud-based IoT enabler.

Review of Technologies

add here subsections related to the Azure and OOI