Dynamic IoT Data, Protocol, and Middleware Interoperability with Resource Slice Concepts and Tools

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ABSTRACT

Dealing with interoperability in the IoT domain is a complex matter that requires various techniques for tackling data, protocol and middleware interoperability. We cannot solve IoT interoperability problems by just developing (new) software components and (semantic) data models. In this tutorial, we will present interoperability techniques for complex IoT Cloud applications by leveraging dynamic solutions of provisioning and reconfiguring of IoT data processing pipelines, protocol bridges, IoT middleware and cloud services. First, the tutorial will examine cross-layered, cross-system interoperability issues and present a DevOps IoT Interoperability approach for defining metadata, selecting resources and software artifacts, and provisioning and connecting resources to create various potential solutions for IoT Cloud interoperability using resource slice concepts. Second, the tutorial will present techniques for dynamically provisioning data pipelines, middleware services, protocol adapters and custom solutions to address cross-layered, cross-system interoperability for IoT Cloud applications. Such solutions also allow dynamic reconfiguration of resources to add/remove interoperability support. We will present the concepts and techniques with hands-on examples using our research tools rsiHub and IoTCloudSamples.

Author Keywords

IoT Interoperability, Resource Slice, Cloud Computing

MOTIVATION

IoT developers and users deal with a variety type of data collected from different sources and these types of data must be processed or provided to other applications. Many software components for IoT data transformation, data messaging, and processing services are involved in even a single IoT Cloud application. Interoperability arises in many aspects and cross layers and systems, not just data or protocol interoperability. Thus, the IoT community has looked for interoperability solutions intensively. In fact, IoT interoperability is one of the hot topics now for researchers and practitioners in academia and industries. We have seen many calls for papers, analyses, tools and projects centered on IoT interoperability. Examples are:

- Unlocking the potential of the Internet of Things, https://www.mckinsey.com/business-functions/digital-mckinsey/our-insights/the-internet-of-things-the-value-of-digitizing-the-physical-world
- The H2020 Inter-IoT project: http://www.inter-iot-project.eu/
- Computing Now Special Issue on IoT Interoperability: https://www.computer.org/web/computingnow/archive/interoperability-in-the-internet-of-things-december-2016-introduction
- IEEE Semantic Interoperability: http://standards.ieee.org/news/2016/semantic_interoperability.html
- Call for papers: Smart End-to-end Massive IoT Interoperability, Connectivity and Security. http://camad2018.ieee-camad.org/smart-end-to-end-massive-iot-interoperability-connectivity-and-security/
- Workshop on Semantic Interoperability in the IoT and WoT (In conjunction with Global IoT Summit 2018)
- 451 Research, The Role of Operational Analytics and Interoperability in the Era of IoT, https://www.intersystems.com/wp-content/uploads/assets/Role_of_Operational_Analytics_and_Interoperability_in_the_Era_of_IoT.pdf
- Opinion: IoT's Interoperability Challenges, https://www.networkworld.com/article/3205207/internet-of-things/iots-interoperability-challenge.html
- https://internetofthingsagenda.techtarget.com/blog/IoT-Agenda/Making-sense-of-IoT-interoperability
- Ken Figueredo, In 2018, Prepare for IoT Interoperability, https://www.rtinsights.com/in-2018-prepare-for-iot-interoperability/, January 4, 2018

- Shao Weixiang, How to make the interoperability of IoT data , https://www.itu.int/en/ITU-T/academia/kaleidoscope/2017/Documents/special/ss03.pdf
- Why IoT Success Hangs on Interoperability, https://www.mouser.com/blog/why-iot-success-hangs-on-interoperability

To understand and solve the IoT interoperability challenge we must view this challenge in a broad perspective. For different developers and users requirements, there are many issues about interoperability, e.g., data interoperability, protocol interoperability and middleware interoperability, which prevent them to develop solutions rapidly. However, often researchers and practitioners just look at one aspect, e.g., data interoperability[1] or protocol bridge[2]. This is due to the focus of their work on a specific part, such as the interface and interactions between sensors and IoT brokers. However, this is also due to the lack of knowledge about how to deal with interoperability of IoT Cloud applications in a holistic way. While many IoT developers and users might not be familiar with all complexity of software services involved in IoT applications, they are faced with the interoperability problems from many places of the whole software chains from IoT data sources to the Cloud backend to the end-user app. Such chains are cross-layers and cross-systems. Therefore, it is of paramount importance for IoT developers and researchers to be aware of diverse types of interoperability problems, seeking and developing novel interoperability solutions in a holistic way.

We have been dealing with IoT Cloud interoperability since many years from a holistic view of software services, protocols, middleware and data within IoT Cloud applications[4][5][6][7][8]. We have seen that existing solutions mainly focus on a particular issue, such as data or protocol, at a particular phase/part of the IoT Cloud applications, e.g., message brokering or data transformation. However, in reality IoT Cloud applications are not just dealing with data formats or protocols. Therefore, we believe that a holistic view on interoperability is crucial. To this end, we can address interoperability through the resource slice of IoT cloud systems: resource slices capture involved components for IoT Cloud applications, and through them, we can identify interoperability problems, add and remove software to support interoperability, and reconfigure existing resources/software to assure interoperability.

Another aspect is that very often we believe that interoperability solution development is static. For example, we identify a problem of interoperability and we spend a lot of effort to build, e.g., a new protocol bridge or a data exchange model. However, we should also see interoperability solutions from another aspect: dynamic and runtime interoperability solutions. This departs from the long-development cycle of standardized components and data models, and leverages existing static, single interoperability solutions. Our interpretation on interoperability is quickly to solve issues that prevents data and software components to be interoperable in specific contexts. Therefore, we investigate runtime solutions and develop DevOps tasks and tools for IoT interoperability to save time and effort to quickly provide context-specific IoT interoperability solutions. Resource slices also enable the rapid development of custom interoperability solutions for specific contexts.

Therefore, we believe that it is extremely important for IoT developers and users to have a very useful tutorial that considers a holistic, integrated view on interoperability across IoT, network functions and clouds for IoT Cloud applications but also examines further runtime solutions, DevOps tasks to foster the development of interoperability solutions in a short time.

We have been building this tutorial based on many years of our research and development. We have started to work on IoT Cloud engineering dealing with IoT data and software. Throughout principles of IoT Cloud engineering, we have identified several issues of interoperable software and data. Subsequently, we have introduced concepts of resource slices and developed various running interoperability solutions for IoT applications. This is also one of contributions in the EU H2020 Inter-IoT project. Especially, our solutions are built atop state-of-the-art IoT Cloud software development, such as we widely use MQTT, Apache Kafka, industrial IoT hubs from Google/Microsoft Azure and Amazon, Docker containers and Kebernetes for running IoT data analytics, streaming analytics with Apache Flink and Kafka for data transformation and processing, Apache Beam, Node-RED and Airflow for data pipelines.

TUTORIAL DESCRIPTION

Content and schedule

The content of this tutorial will include

- IoT Cloud application development overview
- Identification of interoperability problems for IoT data, message brokers, protocols, etc., and review of existing solutions.
- DevOps IoT interoperability model and tools
- Solution approaches to IoT interoperability: static versus runtime solutions.

[1]For example: M. Blackstock and R. Lea, "IoT interoperability: A hub-based approach," 2014 International Conference on the Internet of Things (IOT), Cambridge, MA, 2014, pp. 79-84. doi: 10.1109/IOT.2014.7030119

[2] For example, G. Aloi et al., "A Mobile Multi-Technology Gateway to Enable IoT Interoperability," 2016 IEEE First International Conference on Internet-of-Things Design and Implementation (IoTDI), Berlin, 2016, pp. 259-264.doi: 10.1109/IoTDI.2015.29

- Resource slice model and how to build resource slice that combine various services from IoT, network functions and clouds for IoT Cloud applications
- Metadata for various types of resources for interoperability solutions.
- Runtime IoT interoperability solutions with resource slices:
    - Key changes in IoT Cloud resources metadata description and discovery.
    - Search for interoperable resources.
    - Dynamic provisioning interoperability solutions.
    - Custom data processing functions for dynamic interoperability.
- Practical hands-on examples and solutions using research prototypes IoTCloudSamples [1] and rsiHub [2].

Description of learning outcomes

We believe that the attendees will achieve the following outcomes:

- Understanding the interoperability problems in a holistic and integrated view of IoT Cloud applications.
- Obtaining a state-of-the-art on current IoT interoperability solutions.
- Understanding the complexity of resources required for achieving interoperability for IoT Cloud applications and systems.
- Able to apply, develop and deploy interoperability solutions, especially using existing tools and software, for complex IoT Cloud applications in a rapid and extensible manner.

Presentation style and tutorial format

The tutorial will include presentations and various running examples available in GitHub for hands-on practices. Current examples are available at:

- rsiHub: it includes tools and services for resource slices and interoperability solution development
- IoTCloudSamples: it includes various IoT, network functions and cloud services as samples for resource slices and interoperability

We will develop further examples for this tutorial.

In our plan, the tutorial will be a half day, ideally with 3 hours.

Prior knowledge required by the attendees

Attendees should have basic knowledge about IoT and Cloud, especially able to understand the basic service model and provisioning and common IoT middleware. Attendees should understand the metadata about IoT data and common IoT data format like CSV and JSON. Common knowledge about messaging systems like MQTT, Apache Kafka, and CoAP are expected. It would be a plus if the attendees also knows how to leverage data pipelines and workflows for data transformation. We will use Python and Javascript (with NodeJS) in our examples so basic knowledge about such programming languages are expected.

TUTORIAL MATERIAL

The typical hardware will be laptops as we will utilize existing dataset and virtual machines/dockers to emulate IoT sensors or actually. The software for the tutorial are completely open sources or free. The dataset, tools, etc. are open sources based on our IoTCloudSamples and rsiHub software, whereas some cloud services can be free for the attendees or the attendees can just register such cloud services free. Our software is open source with the Apache 2.0 license.

Furthermore, we commit to release tutorial materials (slides, code examples, etc.) as free open sources hosted in Github under the space https://github.com/rdsea.

AUDIENCE

There is a huge demand on learning how to develop interoperable IoT Cloud applications that leverage IoT, network functions and cloud resources. While it is easy to write IoT applications pushing data to clouds, complex applications require a lot of effort and knowledge about IoT, cloud and network functions across layers and systems. Dealing with interoperability is far from just doing data transformation and building protocol bridges. Thus, this tutorial would be a useful source for not only researchers and practitioners working on IoT systems and data but also for people working on IoT middleware and cloud services. We expect that, with this wide and diverse types of cross concerns, this tutorial will attract both researchers and practitioners.

PRESENTER

The presenter of this tutorial will be

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Hong-Linh Truong received his PhD in 2005 and his Habilitation in 2013 from TU Wien. Currently he is a professor at TU Wien. He lead the Service Engineering Analytics team (rdsea.github.io) in where he concentrates on engineering analytics techniques and tools for designing, monitoring, analyzing, and optimizing functions, performance, data quality, elasticity, and uncertainties associated with systems, software, data and services. He has developed engineering analytics for: Systems (IoT, Cloud, and Edge Systems), Software (Middleware, Protocols, and Tools), Data (Processing Models and Analytics), and

Services (Data Marketplace, Service Models, APIs, and Configuration). His work has been contributed to several EU funded and industry projects and been applied to various applications, including smart cities, smart agriculture, enterprises and telcos. In his teaching, he carries out IoT, cloud computing and advanced services engineering and big data.

In this topic, he has presented several related (invited) talks in NII, Japan (2017), Ericsson Bangalore (2017), IBM Research Almaden (2017), Center of Cyper-physical systems and Internet of Things (CCI) at USC in 2017, Aalto University (2018), and several conference papers. Thus, this tutorial is built on a lot of experiences from previous presentations to create a comprehensive tutorial.

Hong-Linh Truong also carried out several tutorials, including the IEEE CloudCom 2014, the 8th IEEE/ACM International Conference on Utility and Cloud Computing (UCC 2015), and various other tutorials in SummerSoc (Summer School in Service-oriented Computing). Furthermore, this tutorial is also related to the Advanced Services Engineering course (http://www.infosys.tuwien.ac.at/teaching/courses/ase/) that, since many years, he has built for teaching IoT, big data and Cloud services. He has also trained practitioners from industries, such as in the Telco domain, for dealing with IoT and data analytics. Thus, he has experiences in making tutorials for researchers and practitioner.

REQUIREMENT

For this tutorial, we need audio, projector and Internet connection. Attendees can develop solutions in their laptop or cloud environments.

ACKNOWLEDGMENTS

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SOME REFERENCES FOR TUTORIAL MATERIALS

[1] IoTCloudSamples: https://github.com/rdsea/IoTCloudSamples

[2] rsiHub: https://github.com/SINCConcept/HINC

[3] Inter-IoT Project: http://www.inter-iot-project.eu/

[4] Hong-Linh Truong, Nanjangud C. Narendra, Kwei-Jay Lin, Notes on ensembles of IoT, network functions and clouds for service-oriented computing and applications, Service Oriented Computing and Applications Journal, Springer, Mar 2018, Service Oriented Computing and Applications. https://doi.org/10.1007/s11761-018-0228-2

[5] Hong-Linh Truong, Nanjangud Narendra, SINC -- An Information-Centric Approach for End-to-End IoT Cloud Resource Provisioning International Conference on Cloud Computing Research & Innovation, CloudAsia 2016, May 3-5, 2016

[6] Hong-Linh Truong, Towards a Resource Slice Interoperability Hub for IoT, 3rd edition of Globe-IoT 2018: Towards Global Interoperability among IoT Systems, IEEE, 2018. Orlando, Florida, USA, April 17-20, 2018

[7] Hong-Linh Truong, Georgiana Copil, Schahram Dustdar, Duc-Hung Le, Daniel Moldovan, Stefan Nastic, On Engineering Analytics for Elastic IoT Cloud Platforms, The 14th International Conference on Service-Oriented Computing (ICSOC 2016), October 10-13, 2016, Banff, Alberta, Canada

[8] Hong Linh Truong, Schahram Dustdar: Principles for Engineering IoT Cloud Systems. IEEE Cloud Computing 2(2): 68-76 (2015)