University of Stuttgart
Institute for Parallel and Distributed Systems
Applications of Parallel and Distributed Systems

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On Service-Oriented Computing

Enhancing IoT Platforms for Autonomous Device Discovery and Selection

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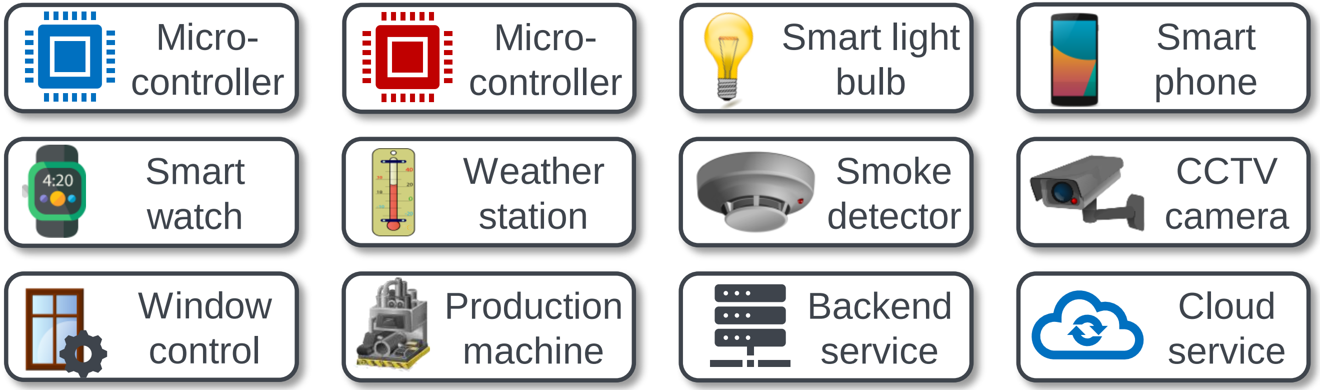
Background & Motivation
IoT ecosystems

- Today, IoT ecosystems can encompass thousands of connected IoT devices
  ≈13 billion IoT devices worldwide in 2022, ≈30 billion predicted for 2030 [1]
  ≈0.5 devices per m^2 necessary in smart factories [2]
- Each device may be equipped with sensors and actuators
- All devices of an ecosystem may need to interact in order to achieve common goals

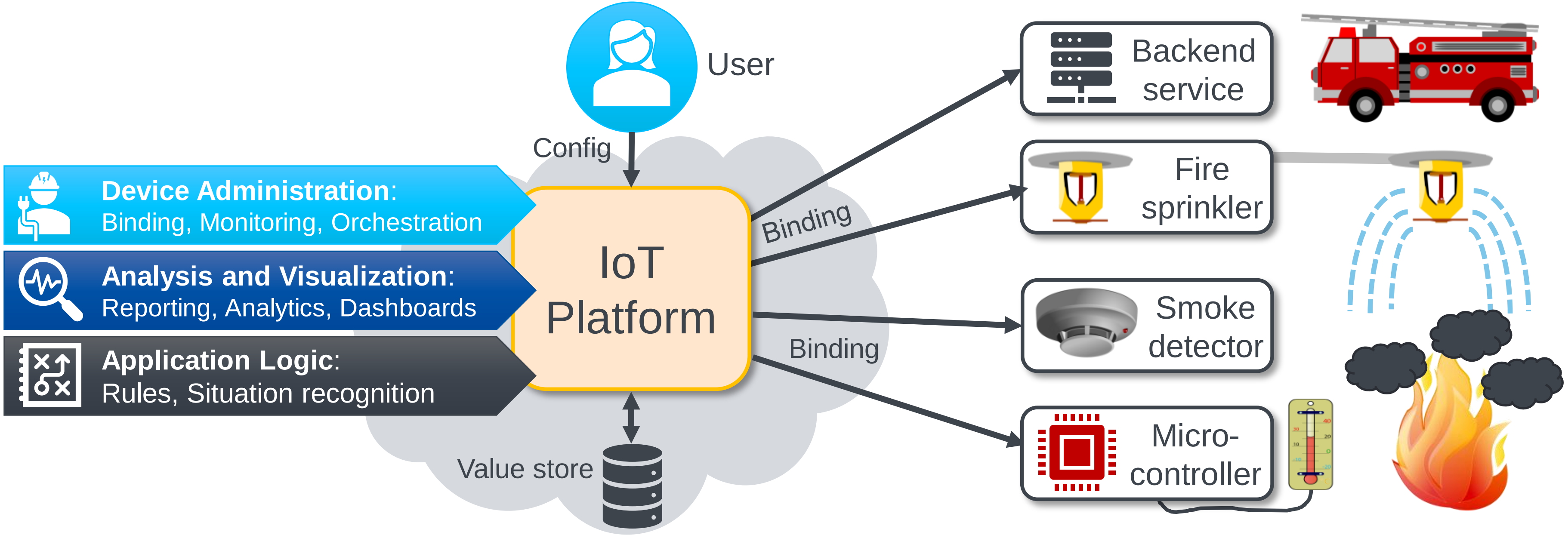


Challenges:
- Complexity
- Heterogenity
- Dynamics

[1] Statista GmbH. (2022, May). “Number of Internet of Things (IoT) connected devices worldwide from 2019 to 2030“.
[2] Telefonaktiebolaget L. M. Ericsson. (2018). “Ericsson Mobility Report June 2018“.

Background & Motivation
IoT platforms

- To cope with these challenges, *IoT platforms* [3] have emerged
- Provide tools to ease the management of IoT ecosystems



[3] Guth, J. et al. (2016). Comparison of IoT platform architectures: A field study based on a reference architecture. In 2016 CIoT. IEEE.

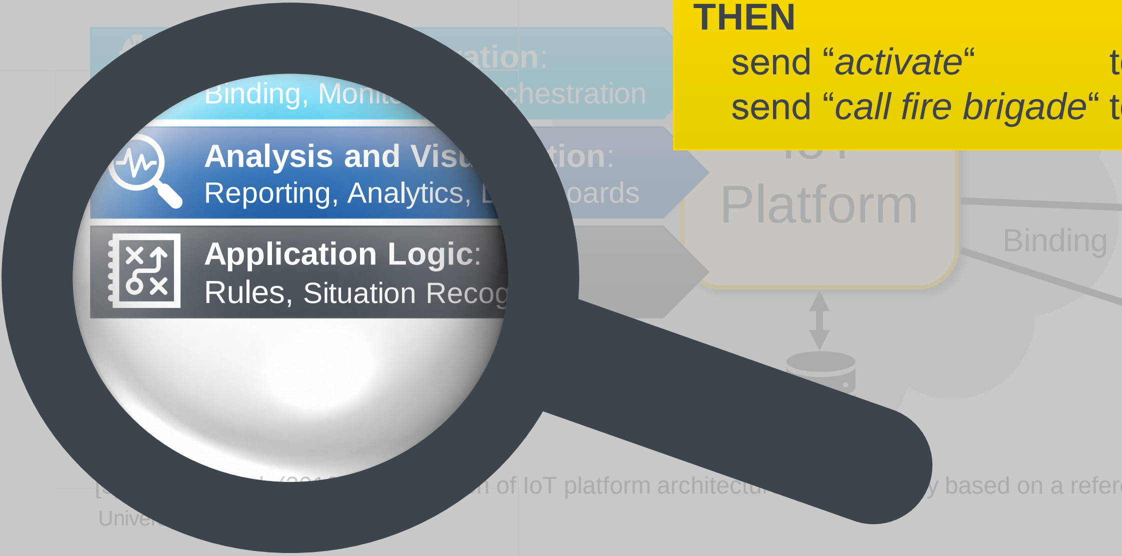
Background & Motivation
IoT platforms

- To cope with these challenge
- Provide tools to ease the ma

Application logic for rule *FIRE* (simplified)

IF
value of [device 192.168.0.1] > 40
AND
value of [device 192.168.0.2] == “smoke“

THEN
send “*activate*“ to [device 192.168.0.3]
send “*call fire brigade*“ to [device 192.168.0.4]



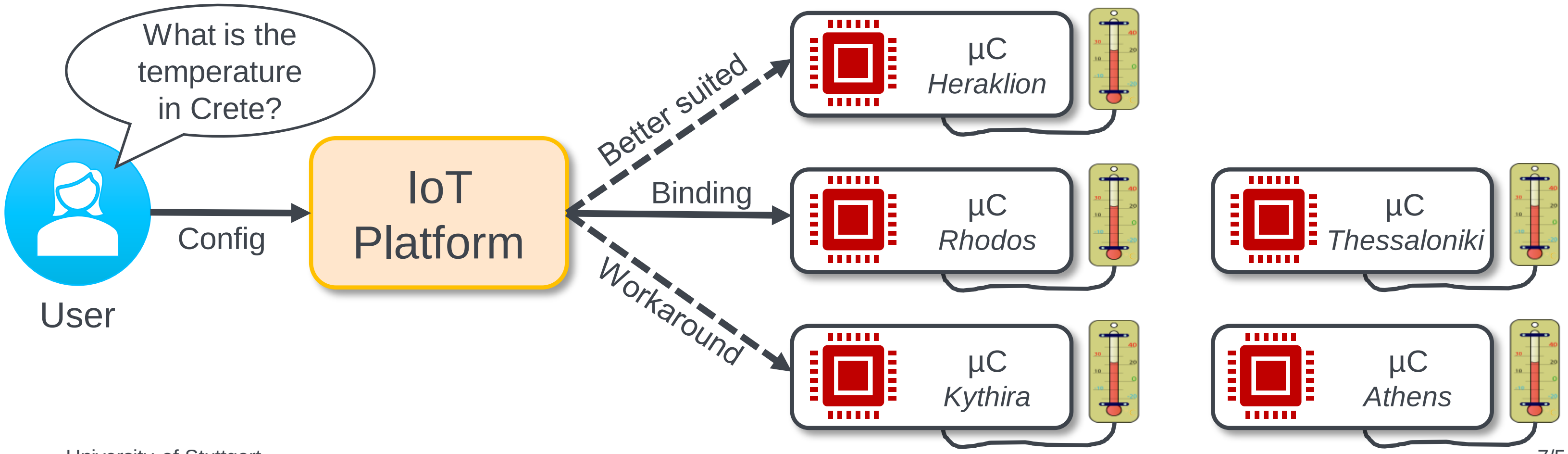
IP addresses or other unique identifiers refer to exactly one physical device

[... of IoT platform architectu... y based on a reference architecture. In 2016 CIoT. IEEE.

Background & Motivation
Shortcomings of static device references

- Users need to select devices for use cases on their own
- What if the device reference changes (e.g. dynamic IP addresses)?
- What if the selected device fails or leaves the ecosystem?
- What if a device joins the ecosystem that is even better suited for the use case?

Huge manual maintainance efforts, infeasible for large ecosystems



Literature review
Shortcomings of existing discovery approaches

- **Device discovery** approaches allow to autonomously find devices within an IoT ecosystem
- Device and service discovery are well-established fields
  → we reviewed > 30 discovery approaches related to the IoT
- However, they exploit specific characteristics of the communication infrastructure and the involved devices
  → only applicable to ecosystems supporting these technologies
- IoT platforms intend to be rather **universally applicable** and are not tailored towards individual ecosystems
  → adaption of *some* approaches would severely limit their applicability

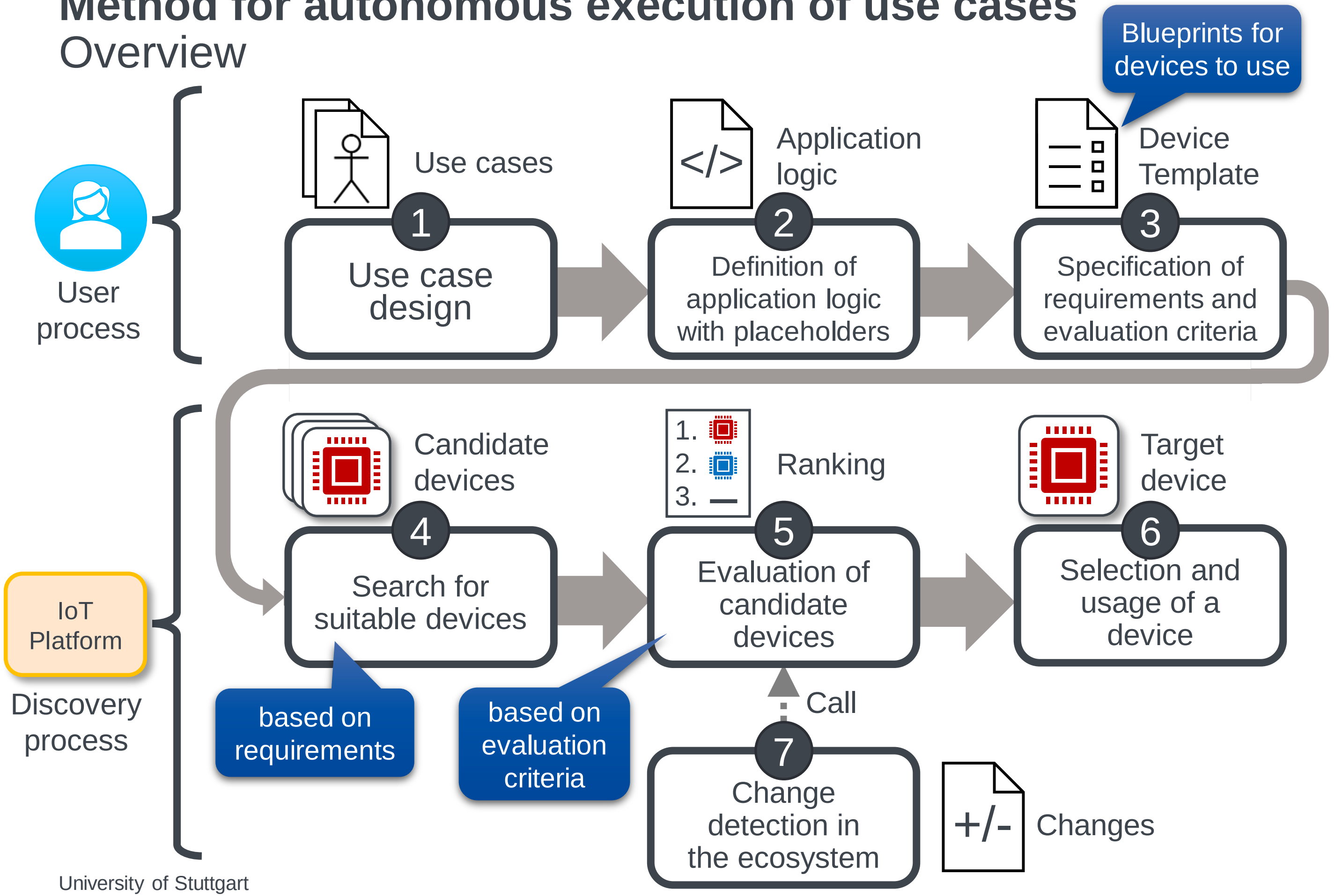
	CR	D	S	M	IN	K	C	R	Q	Technologies	Device Description
[42]	single	✗	✗	✓	unspec.	✓	✗	✗	s	REST	SensorML
[53]	single	✗	✓	✗	device	✗	✓	✓	s	SOA stack	WSDL, QoS readings
[2]	single	✗	✗	✗	device	✗	✗	✗	-	CoAP, CoRE-RD	comm. behaviour
[16]	federated	✗	✗	✓	device	✓	✓	✗	s	DNS-SD	DNS names, TXT-RRs
[31]	per ecosys.	✓	✗	✗	device	✗	✓	✗	s	CoAP, CoRE-RD, P2P	(range) attributes
[12]	none	✓	✗	✗	device/P2P	✗	✓	✓	s	unstructured P2P	QoS attributes
[36]	single	✗	✗	✗	device or IoT hub	✗	✗	✗	-	SSDP/UPNP, HTTP, MQTT	JSON
[33]	single	✗	✓	✓	user	✓	✗	✓	s	REST	JSON-LD
[4]	per gateway	✗	✗	✗	device	✓	✗	✗	s	DNS-SD, mDNS, CoAP, 6LoWPAN	resource records
[6]	arbitrary	✓	✗	✓	device	✓	✓	✗	b	DNS-SD, mDNS, CoAP, JSONPath, SPARQL	WoT Thing Description
[10]	Blockchain	✗	✗	✓	provider	✗	✓	✗	s	SPARQL	SSN/SOSA extension
[17]	federated	✗	✗	✓	user	✗	✓	✗	b	MQTT, SPARQL	SSN, SAN, OWL-S
[43]	none	✗	✗	✗	scanner	✗	✗	✗	-	network/port scanner	open network ports
[40]	per sniffer	✓	✗	✗	device	✗	✗	✗	b	MQTT, multicast	JSON
[49]	none	✓	✗	✗	device	✗	✓	✗	s	unspecified	feature list
[13]	arbitrary	✓	✗	✗	device	✓	✓	✗	s	CoAP, CoRE-RD, P2P	e.g. CoRE Link Format
[39]	single	✗	✗	✗	device	✗	✗	✗	-	HTTP proxy	XML, JSON
[50]	per gatew.	✓	✗	✗	device	✓	✗	✗	b	CoAP, CoRE-RD, P2P	CoRE Link Format
[1]	federated	✗	✗	✗	device	✓	✗	✗	s	CoAP, CoRE-RD	JSON
[14]	per router	✓	✗	✗	device	✓	✗	✗	s	ICN, CoAP	CoRE Link Format
[27]	single	✗	✓	✗	device	✗	✗	✗	-	DPWS, multicast, MQTT	JSON
[5]	single	✗	✗	✓	user	✗	✓	✗	s	SPARQL	custom ontology
[26]	single	✗	✗	✗	device	✓	✓	✗	s	REST, Bluetooth, ZigBee, Wi-Fi	JSON
[18]	federated	✗	✗	✓	user	✗	✓	✗	b	SPARQL	SSN, SAN, OWL-S
[32]	single	✗	✓	✗	user/MW	✓	✗	✓	s	SOA middleware	XML
[47]	single	✗	✗	✓	device	?	✓	?	s	X-GSN, SPARQL	SSN extension
[9]	single	✗	✗	✗	device	✓	✗	✓	s	REST, LWM2M, CoAP	CoRE Link Format
[30]	none	✓	✗	✓	n.a.	✓	✓	✓	s	P2P Skipnet	context ontologies
[7]	per gateway	✓	✗	✗	device or gateway	✓	✗	✗	s	DNS-SD, mDNS, P2P, CoAP	CoRE Link Format or JSON-WSP
[28]	arbitrary	✓	✗	✗	device	✓	✗	✗	b	DNS-SD, mDNS, Bonjour	TXT-RR
[20] [3]	single	✗	✓	✗	device or disc. unit	✓	✓	✓	s	WS-Discovery, DPWS, multicast	WSDL
[48]	federated	✗	✗	✓	device	✓	✓	✗	s	AtomPub, mDNS	Atom Syndic. Format

Our Contribution
Overview

To overcome these issues, we propose…

1. A **method** allowing IoT platforms to execute pre-defined use cases in IoT ecosystems
   - By dynamically discovering and selecting the most suitable devices
   - Autonomously and reliably
2. An **architecture** supporting this method
   - Introduces an abstraction layer to decouple IoT platforms from the ecosystems
   - Avoids that the IoT platform imposes major constraints on the ecosystem in which it is operated

Method for autonomous execution of use cases
Overview



App. logic for rule *FIRE*

IF
value of [DEV_A] > 40
AND
value of [DEV_B] == “smoke“

THEN
send “*activate*“ to [DEV_C]

Device Template *DT_1*

Requirements:
- Located in production hall
- Has temperature sensor

Evaluation criteria:
- Small observational error
- Availability

DT_1 attached to DEV_A

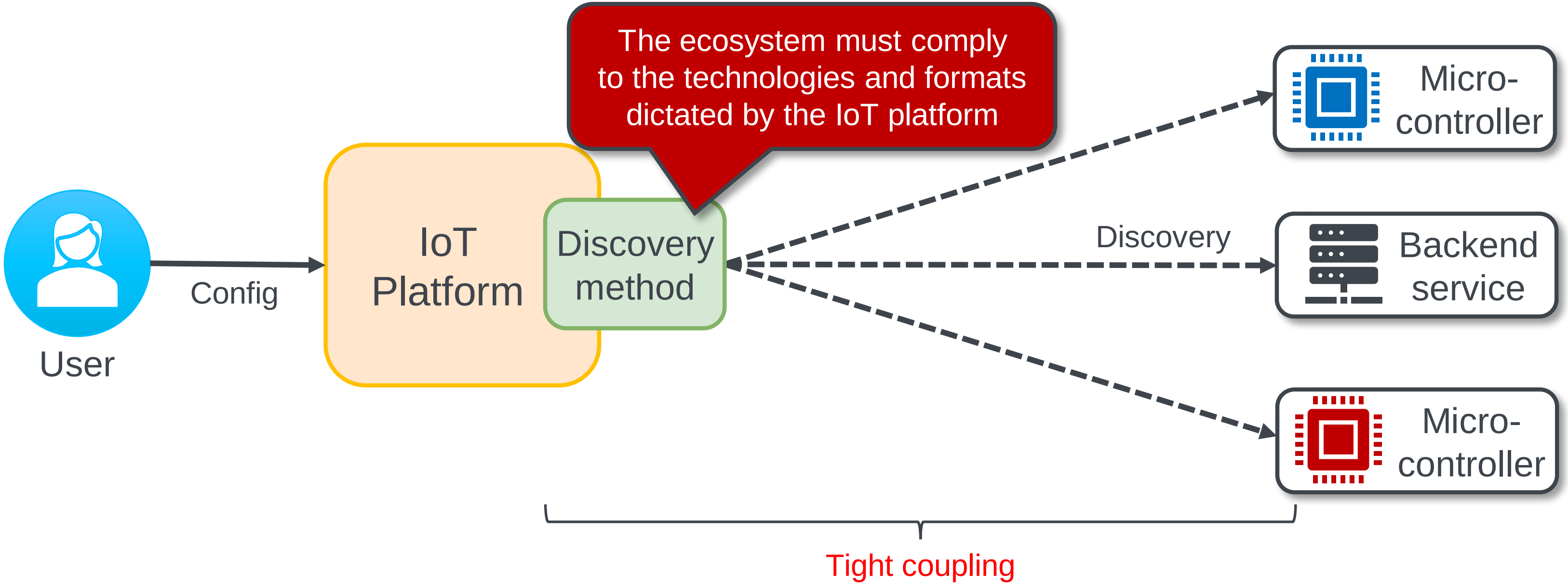
Method for autonomous execution of use cases
Summary

- Ensures that always **the most suitable** available devices are utilized by the IoT platform
- Detects changes in the ecosystem and handles them:
  - Devices leaving the ecosystem
  - New devices joining the ecosystem
  - Capability changes of devices

} Re-evaluation of candidate devices and adaption of target devices if necessary

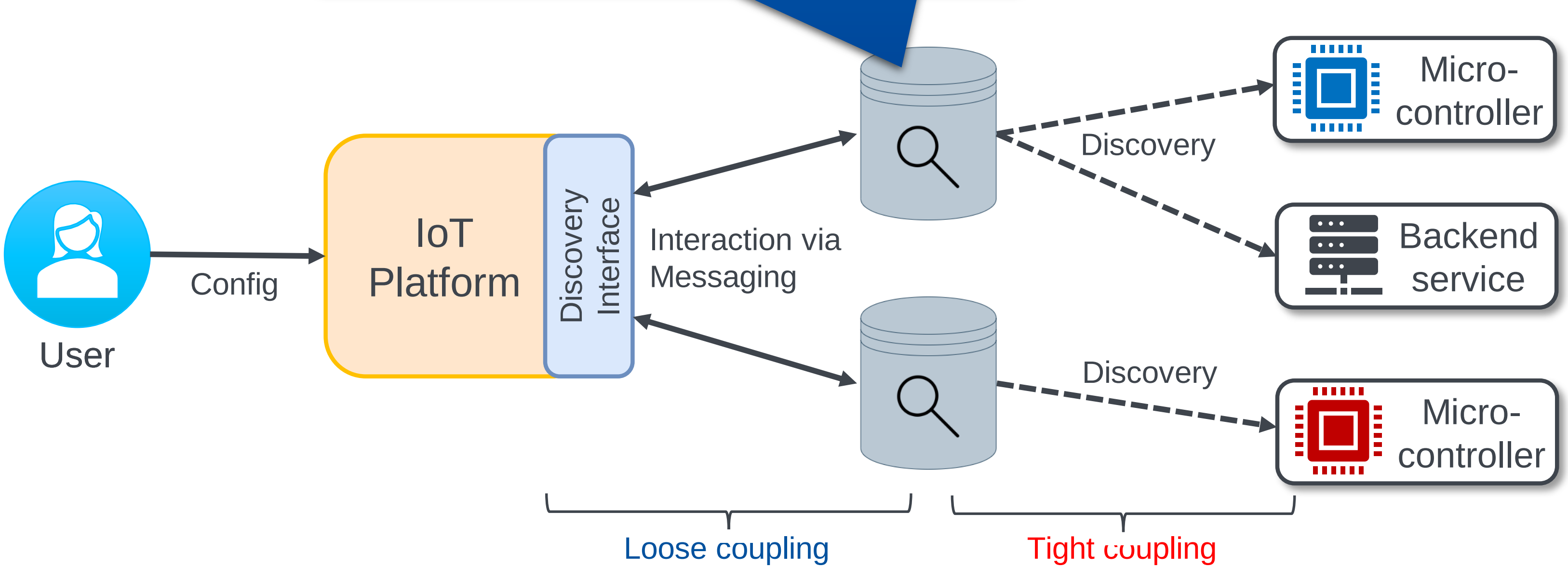
Supporting Architecture
Overview

- Step 4 and 7 rely on a discovery approach for finding devices matching the requirements
- However, discovery approaches from literature would limit the applicability of the IoT platform → Loosely-coupled architecture for more flexibility

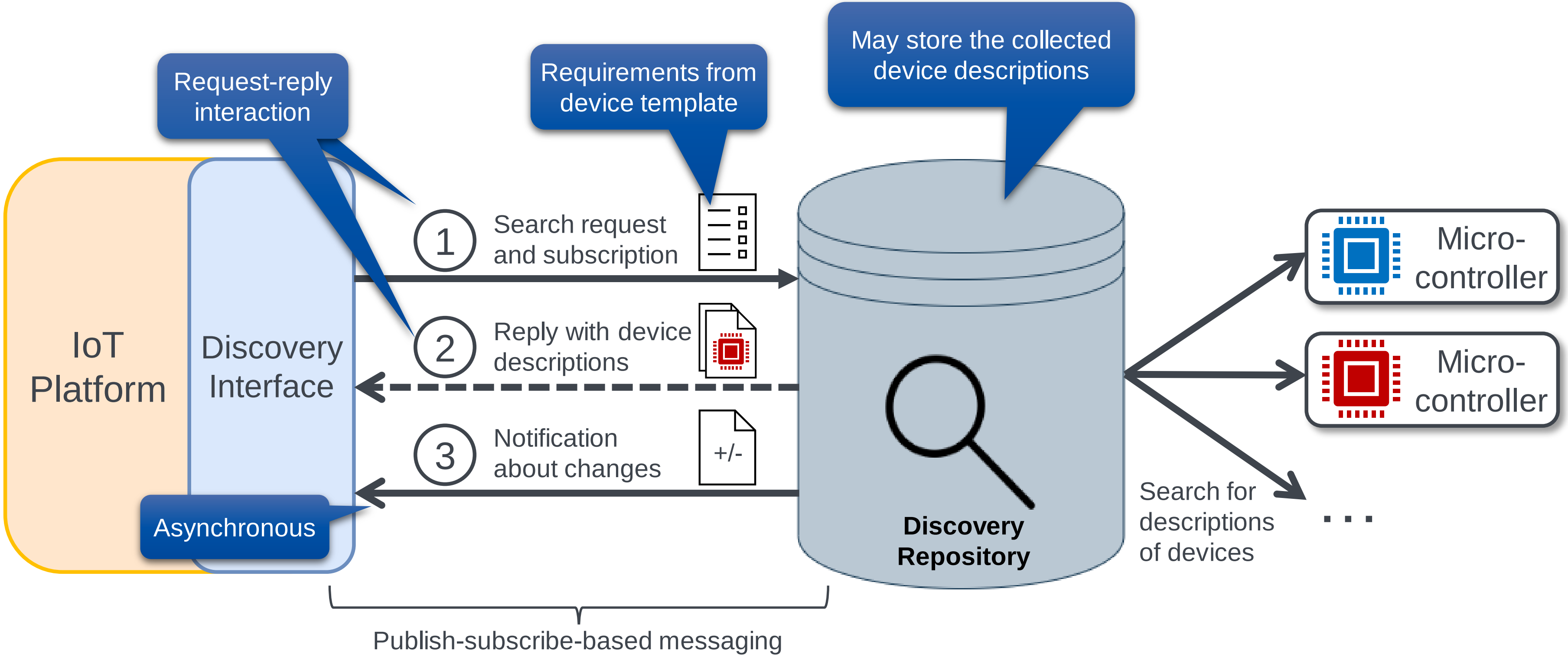


Supporting Architecture
Overview

Discovery Repositories (DRs):
- Provided by the owners of the ecosystem
- Encapsulate technology-specific aspects and offer a pre-defined interface to the IoT platform

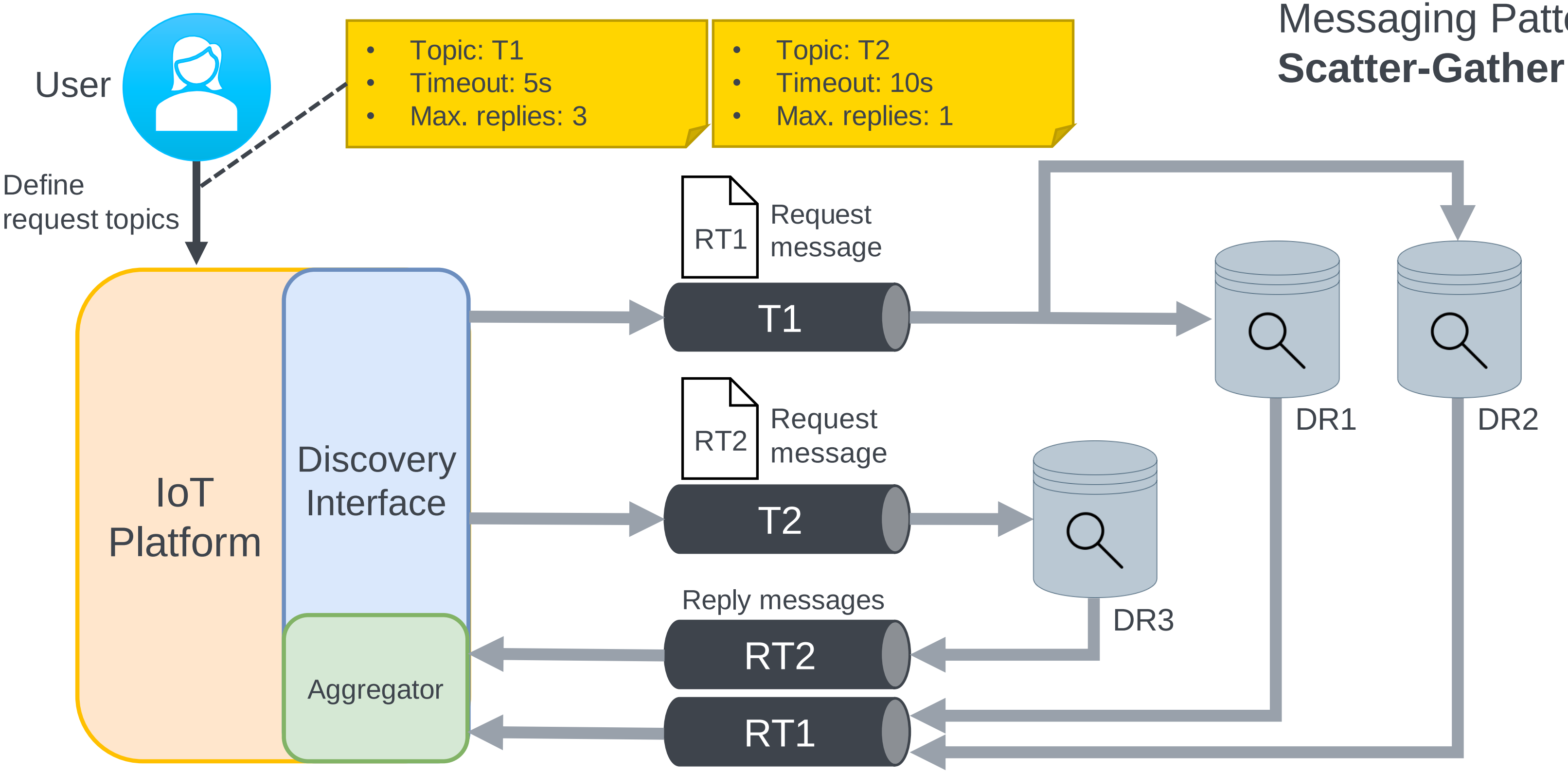


Supporting Architecture
Discovery Repositories



Supporting Architecture
Request-reply interaction

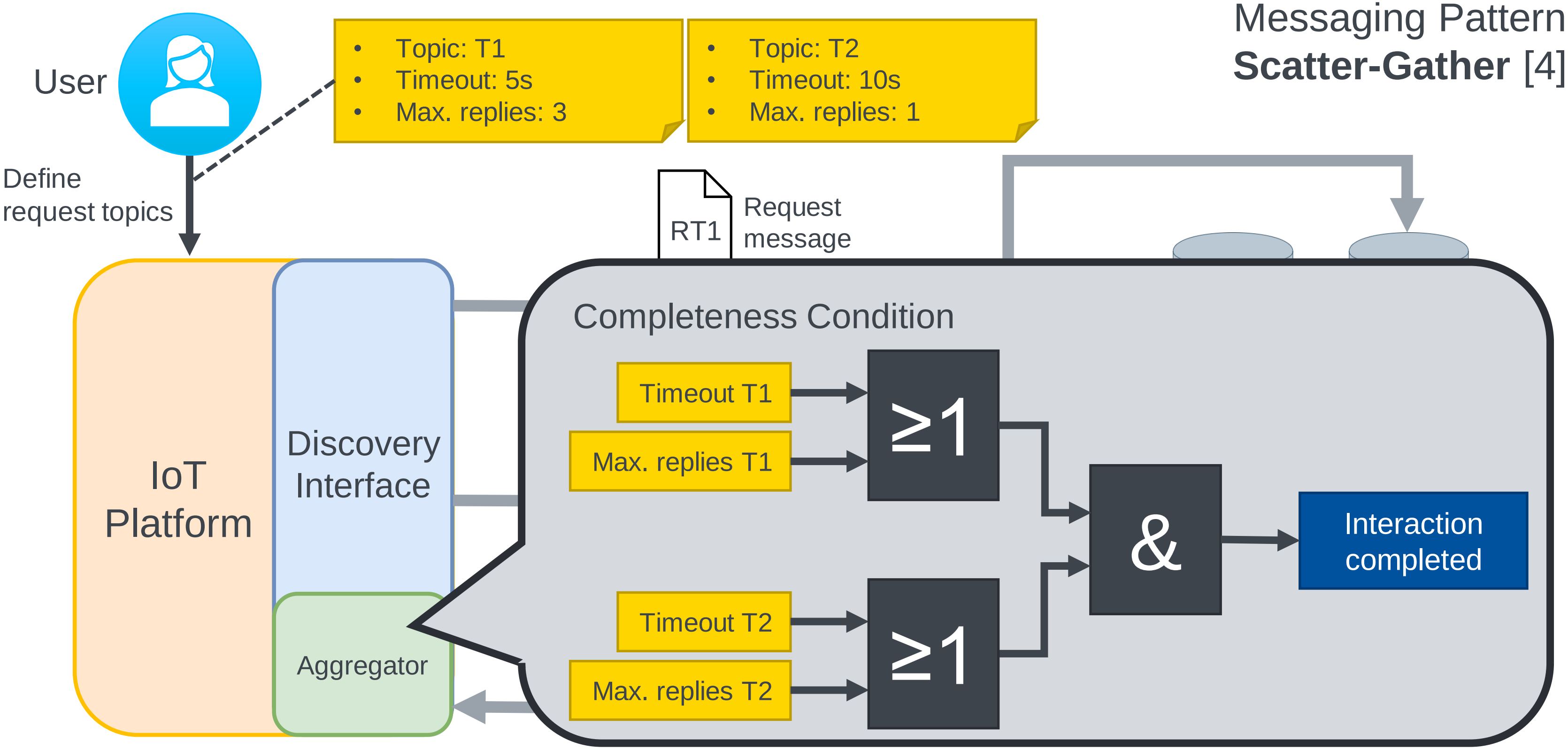
Messaging Pattern
Scatter-Gather [4]



[4] Hohpe, G. & Woolf, B. (2004). Enterprise integration patterns: Designing, building, and deploying messaging solutions. Addison-Wesley Professional.

Supporting Architecture
Request-reply interaction

Messaging Pattern
Scatter-Gather [4]



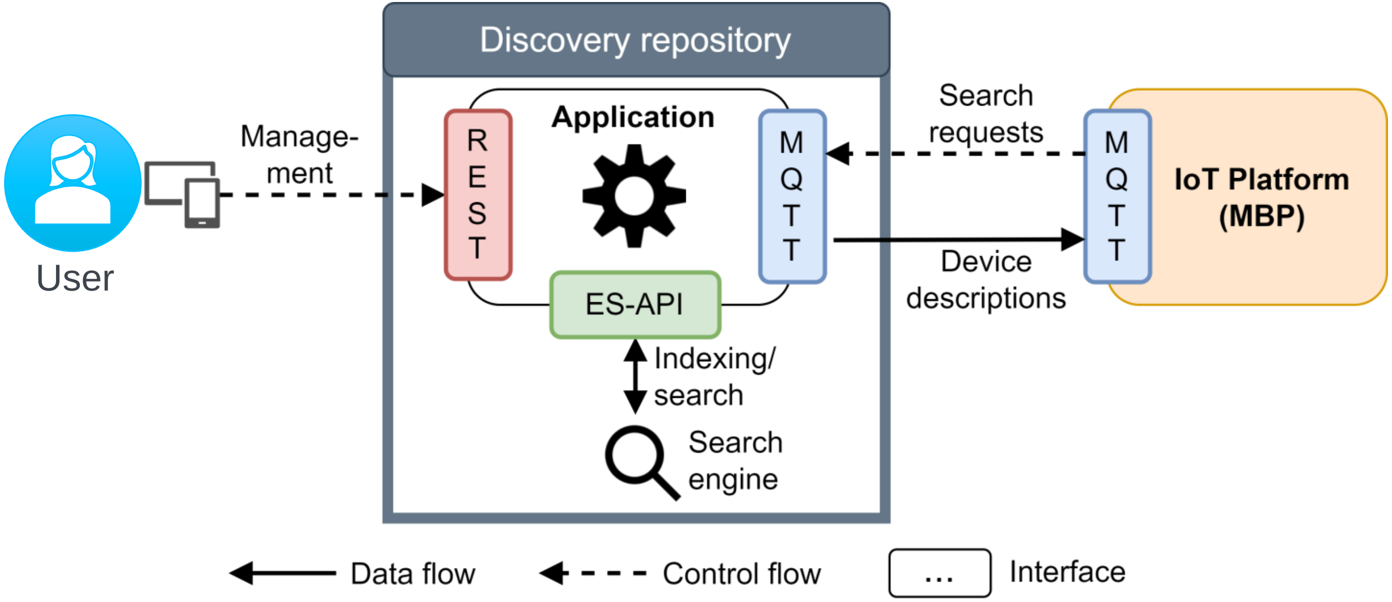
[4] Hohpe, G. & Woolf, B. (2004). Enterprise integration patterns: Designing, building, and deploying messaging solutions. Addison-Wesley Professional.

Supporting Architecture
Properties

- Discovery Repositories (DRs) hide technology-specific aspects from the IoT platform → **flexibility**
- Increasing number of devices can be countered by the deployment of additional DRs, without adjustments to the IoT platform → **scalability**
- Device descriptions can be made redundantly available in multiple DRs → **availability**
- **But**: The DRs need to be developed first → **efforts**

Prototype (Proof of Concept)
Overview

- Integrated the presented method into a IoT platform [5] developed by our department
- Exemplary Discovery Repository, interacting with the IoT platform



[5] da Silva, A. C. F. et al. (2020). MBP: Not just an IoT platform. In 2020 PerCom. IEEE.

Summary & Outlook

We propose…

- a **method** allowing IoT platforms to autonomously and reliably execute pre-defined use cases within IoT ecosystems by discovering and selecting the most suitable devices
- an **architecture** supporting this method, introducing Discovery Repositories as additional abstraction layer between the IoT platform and the devices to achieve loose coupling

Result: Overcomes the issue of static references by dynamically finding suitable devices

Future Work:

- Tests in larger IoT ecosystems to empirically verify the results
- Inclusion of availability predictions into the evaluation of candidate devices

Thank you!

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