The preliminary results of a mapping study of deployment and orchestration for IoT*

Phu H. Nguyen, Nicolas Ferry
Gencer Erdogan, Hui Song
SINTEF
Oslo, Norway
first.last@sintef.no

Stéphane Lavirotte
Jean-Yves Tigli
Université Côte d'Azur, CNRS, I3S
Nice, France
first.last@unice.fr

Arnor Solberg
TelluIoT
Oslo, Norway
first.last@tellu.no

ABSTRACT

IoT systems are typically distributed and performing coordinated behavior across IoT, edge and cloud infrastructures. To fully realize the great potential of IoT systems, it is important to facilitate their creation and operation. It is crucial to have a clear picture of the research landscape of the existing approaches and tools for supporting the deployment and/or orchestration of IoT systems (Depo4IoT). Such a picture can show us how advanced the current state of the art is and what are the gaps to address. We conducted a systematic mapping study (SMS) to find out the research landscape in this domain. The results of our SMS show a sharp increase in the number of primary Depo4IoT publications in two recent years. We found that most approaches do not really support the deployment or orchestration at IoT devices level. Finally, we suggest some potential research directions to address the research gaps that have been found.

CCS CONCEPTS

• **General and reference → Surveys and overviews**;

KEYWORDS

IoT, review, survey, deployment, orchestration, trustworthiness

ACM Reference Format:
Phu H. Nguyen, Nicolas Ferry, Gencer Erdogan, Hui Song, Stéphane Lavirotte, Jean-Yves Tigli, and Arnor Solberg. 2019. The preliminary results of a mapping study of deployment and orchestration for IoT. In *The 34th ACM/SIGAPP Symposium on Applied Computing (SAC '19), April 8–12, 2019, Limassol, Cyprus.* ACM, New York, NY, USA, Article 4, 4 pages. https://doi.org/10.1145/3297280.3297617

1 INTRODUCTION

The world is now on the verge of "the IoT age" with the Internet of Things (IoT) installed units predicted to grow to 20.4 billion by 2020[1]. IoT systems can be classified as systems of systems in which physical systems (a.k.a, "things") and cyber systems are combined and connected via connection means. Despite having enormous potential, the heterogeneous nature of IoT brings up great challenges that must be addressed to fully realize the potential of the IoT. Because IoT systems are typically distributed and performing coordinated behavior across IoT, edge and cloud infrastructures [1], it is important to facilitate their creation and operation. Research community and industry have been proposing different approaches and tools for supporting the deployment and/or orchestration of IoT systems. However, it is not clear what are the primary existing approaches for supporting the deployment and/or orchestration of IoT systems, and how advanced they are.

To provide a clear picture of the research landscape of the existing approaches and tools for supporting the deployment and/or orchestration of IoT systems (Depo4IoT), we conducted a systematic mapping study (SMS). Specifically, the aim of our SMS is three-fold. First, we want to summarize the existing primary Depo4IoT approaches. Second, by analyzing the existing approaches, we can identify any gaps in the state-of-the-art. Third, based on the results, we propose new research activities to fill the gaps for supporting modern IoT systems. We followed the latest guidelines in [5] to conduct our SMS. We have systematically filtered thousands of relevant papers from four main on-line publication databases, and a manual search process, to finally obtain a set of *sixty nine* (69) primary Depo4IoT studies. We extracted and synthesized data from the primary studies to answer our research questions. The main contributions of this work are our answers to the following research questions. **RQ1**: *What are the publication statistics of the primary Depo4IoT studies?* **RQ2**: *What are the primary Depo4IoT approaches and how advanced are they?* **RQ3**: *What are the open issues to be further investigated in this field?*

In the remainder of this paper: Section 2 presents our SMS approach. We show the results of our SMS in Section 3. This SMS is compared with related work in Section 4. Finally, we conclude the paper in Section 5.

2 OUR SYSTEMATIC MAPPING APPROACH

We conducted our SMS by following the latest guidelines for conducting SMS in [5]. To explicitly define the scope of our SMS and reduce possible bias in our selection process, in Section 2.1, we clarify the inclusion/exclusion criteria for selecting primary studies. Section 2.2 shows our search strategy to find the primary studies for answering the RQs.

2.1 Inclusion and exclusion criteria

Based on the research questions and the scope of our study presented in Section 1, we clearly predefined the inclusion and exclusion criteria to reduce bias in our process of search and selection of

*Supported by the H2020 programme under grant agreement no 780351 (ENACT).
[1]Gartner, February 7, 2017

SAC '19, April 8–12, 2019, Limassol, Cyprus

ACM ISBN 978-1-4503-5933-7/19/04.
https://doi.org/10.1145/3297280.3297617

primary studies. The primary studies must meet ALL the following inclusion criteria (IC):
- (IC1) Must propose a deployment OR orchestration approach.
- (IC2) Must be explicitly for IoT area, either in general or in a specific application domain of IoT.
- (IC3) Must have software engineering approaches as software is the main drive of deployment and orchestration for IoT.

We excluded non-peer-reviewed or unpublished paper, white paper, technical report, thesis, patent, general web page, presentation, book chapter, and paper not written in English.

2.2 Search strategy and selection process

Using the online search functions of popular publication databases is the most common way to search for primary studies when conducting secondary studies [5]. In Section 2.2.1, we present our database search process. To complement for the database search process, we have also conducted a manual search process presented in Section 2.2.2. Fig. 1 shows an overview of the search and selection process with the results for each step, which we describe as follows.

2.2.1 Database search. We used four popular publication databases IEEE Xplore[2], ACM DL[3], Science Direct[4], and Scopus[5] to search for candidates of primary studies. We did not use Google Scholar and SpringerLink. Scopus and ACM DL already index SpringerLink[6] [7]. Google Scholar returns all kinds of papers, in which peer-reviewed articles should have been covered by our four chosen databases. Worse, Google Scholar also returns many non-peer-reviewed and non-English papers, which should have been excluded at the first place. The four chosen databases contain peer-reviewed articles, and provide advanced search functions, especially search in metadata such as title, abstract, keywords that we used. Based on the research questions, we identified the search keywords. Basically, we used the following search query: *("Internet of Things" OR IoT OR "Web of things" OR WoT) AND (orchestration OR deployment OR choreography OR topology OR composition OR dataflow) AND (Tool OR Middleware OR Service OR Framework)*. The search string needs to be applied according to the search functions provided.

For each candidate paper, we first read the paper's title, keywords and abstract. If a paper appears in more than one database, we only kept the original one in where it was published first. If the title, keywords and abstract are insufficient for us to exclude a paper, we further skimmed and scanned its full content. We rather kept any candidate paper in doubt at one point for further checks later. In the end, we hold discussions among reviewers to crosscheck the candidate papers in doubt and agreed on including or excluding each paper. After group discussions, we obtained 63 primary studies.

2.2.2 Manual search. We started our manual search by initiating a set of the Depo4IoT studies that we have known of, *e.g.*, the studies numbered 22, 24, 26, 30, 31, 35, 42, 49, 50, 53, 55 in Table 1. This was the test set to fine-tune the search query in the automatic search. Moreover, we checked the latest work of the authors of these Depo4IoT studies and their related work to find more Depo4IoT studies (using Google scholar). We found six new primary studies that have not been found in the automatic search process (because the common keywords are not in their titles and abstracts). In total, we obtained the final set of 69 primary studies[7] for data extraction and synthesis to answer our research questions.

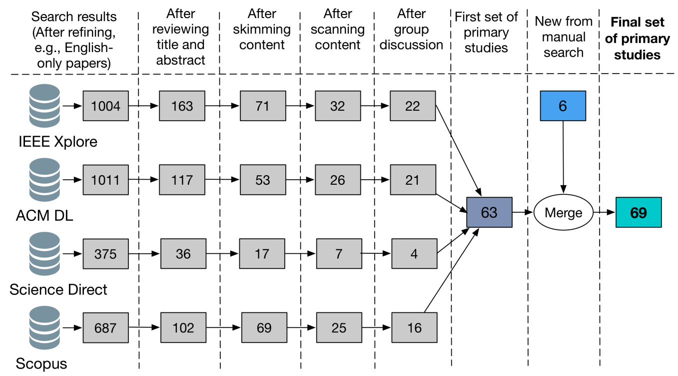

Figure 1: Overview of the search and selection steps

3 RESULTS

Table 1 shows an overview of the primary Depo4IoT studies. We have extracted and synthesized the data from the primary studies to answer the research questions.

3.1 RQ1: General aspects

As we can see in Fig. 2, the earliest primary study was published in 2008, when IoT research started to emerge. There is a sharp rise in the number of Depo4IoT publications in the last two years (2016, 2017), especially regarding the numbers of journal (J) and conference (C) papers (2016: 3J, 6C and 2017: 7J, 18C). This rise shows the crucial need of Depo4IoT research and more attention to this research area has gained from the research community. We completed our search process in March 2018 and already found five primary studies published in 2018 (3J, 2C).

Looking at the affiliations of the authors, Fig. 3 shows that a majority of the authors publishing results on Depo4IoT are academics (86%). The involvement of industry in this research is still very limited, which is understandable for a relatively new research area like IoT. Regarding the types of case studies used for evaluating the Depo4IoT approaches, Fig. 4 also shows the similar dominance of pure academic approaches (78%). We classify the case studies that are not from industry as academic ones, *e.g.*, motivational examples, prototypes or simulations developed by researchers for discussing or evaluating their Depo4IoT approaches. Nearly one tenth of the studies do not really provide evaluation details (not available, N/A) because of the early stage of their work, *e.g.*, reported in short papers or new ideas papers. But, the number of industrial case studies or empirical studies (with industry) account for 13% in total, which is still encouraging. We would call for more collaboration between academia and industry for more practical Depo4IoT research in particular, but also IoT research in general.

[2] http://ieeexplore.ieee.org
[3] https://dl.acm.org
[4] https://www.sciencedirect.com
[5] https://www.scopus.com
[6] https://www.springer.com/gp/computer-science/lncs/information-on-abstracting-and-indexing/799288
[7] Our search and selection process for the primary studies ended on 16 March 2018

Table 1: An overview of the primary Depo4IoT studies (sorted by year of publication)

#	*Title**	*Year*	v	f
1	Challenges and Solutions in Fog Computing Orchestration	2018	J	O
2	Deploying Edge Computing Nodes for Large-scale IoT: A Diversity Aware Approach	2018	J	D
3	Cloud-Fog Interoperability in IoT-enabled Healthcare Solutions	2018	C	D
4	A visual programming framework for distributed Internet of Things centric complex event processing	2018	J	B
5	Enhancing Middleware-based IoT Applications through Run-Time Pluggable QoS Management Mechanism	2018	C	D
6	A Dynamic Module Deployment Framework for M2M Platforms	2017	C	D
7	A Middleware for Mobile Edge Computing	2017	J	B
8	A service orchestration architecture for Fog-enabled infrastructures	2017	C	O
9	Distributed Orchestration in Large-Scale IoT Systems	2017	C	O
10	Internet of Things: From Small- to Large-Scale Orchestration	2017	C	O
11	QoS-Aware Deployment of IoT Applications Through the Fog	2017	J	D
12	Service Orchestration in Fog Environments	2017	C	O
13	Towards Container Orchestration in Fog Computing Infrastructures	2017	C	O
14	A Framework based on SDN and Containers for Dynamic Service Chains on IoT Gateways	2017	W	D
15	A framework for MDE of IoT-Based Manufacturing CPS	2017	C	O
16	A Novel Service-Oriented Platform for the Internet of Things	2017	C	O
17	Design and Implementation of a Message-Service Oriented Middleware for Fog of Things Platforms	2017	C	O
18	Empowering End Users to Customize their Smart Environments	2017	J	O
19	Feasibility of Fog Computing Deployment based on Docker Containerization over RaspberryPi	2017	C	B
20	Semantics Based Service Orchestration in IoT	2017	C	O
21	An Object-Oriented Model for Object Orchestration	2017	C	B
22	A TOSCA-based Programming Model for Interacting Components of Automatically Deployed Cloud and IoT Applications	2017	C	B
23	An edge-based platform for dynamic Smart City applications	2017	J	D
24	Calvin Constrained: A Framework for IoT Applications in Heterogeneous Environments	2017	C	B
25	InterCloud Communication Through Gatekeepers to Support IoT Service Interaction in the Arrowhead Framework	2017	J	O
26	Internet of things out of the box Using TOSCA for automating the deployment of IoT environments	2017	C	B
27	Platform-as-a-service gateway for the Fog of Things	2017	J	B
28	Runtime deployment and management of CoAP resources for the internet of things	2017	J	D
29	Composing Continuous Services in a CoAP-based IoT	2017	C	B
30	Niflheim: An end-to-end middleware for applications on a multi-tier IoT infrastructure	2017	C	B
31	Foggy- A Framework for Continuous Automated IoT Application Deployment in Fog Computing	2017	C	D
32	A Web of Things Based Device-Adaptive Service Composition Framework	2016	C	O
33	Application Orchestration in Mobile Edge Cloud: Placing of IoT Applications to the Edge	2016	W	O
34	Optimizing Elastic IoT Application Deployments	2016	J	D
35	FRED- A Hosted Data Flow Platform for the IoT built using NodeRED	2016	W	B
36	Incremental deployment and migration of geo-distributed situation awareness applications in the fog	2016	C	D
37	On Building Smart City IoT Applications- a Coordination-based Perspective	2016	W	B
38	Orchestrating the Internet of Things Dynamically	2016	W	B
39	SoIoT: Toward A User-Centric IoT-Based Service Framework	2016	J	O
40	A Container-based Edge Cloud PaaS Architecture-based on Raspberry Pi Clusters	2016	C	B
41	Automated Deployment of SmartX IoT-Cloud Services based on Continuous Integration	2016	C	D
42	Cloud4IoT: A Heterogeneous, Distributed and Autonomic Cloud Platform for the IoT	2016	C	B
43	Reliable services composition method for the internet of thing using directed service-object graph deployment scheme	2016	C	O
44	Integration of Heterogeneous Services and Things into Choreographies	2016	W	O
45	A Scalable Framework for Provisioning Large-Scale IoT Deployments	2016	J	D
46	A Data-Centric Framework for Development and Deployment of Internet of Things Applications In Clouds	2015	C	D
47	Towards a Semantic Model for Automated Deployment of IoT Services across Platforms	2015	C	D
48	A component based approach for the Web of Things	2015	W	O
49	A Generic Service Oriented Software Platform to Design Ambient Intelligent Systems	2015	C	O
50	Developing IoT Applications in the Fog: a Distributed Dataflow Approach	2015	C	B
51	A Full End-to-End Platform as a Service for Smart City Applications	2014	W	B
52	A Novel Deployment Scheme for Green Internet of Things	2014	J	D
53	glue.things - a Mashup Platform for wiring the Internet of Things with the Internet of Services	2014	W	B
54	Toward a Distributed Data Flow Platform for the Web of Things	2014	W	O
55	BeC3: Behaviour Crowd Centric Composition for IoT applications	2014	J	B
56	Dioptase: a distributed data streaming middleware for the future web of things	2014	J	B
57	Application deployment for IoT: An infrastructure approach	2013	C	B
58	Orchestration in distributed web-of-objects for creation of user-centered iot service capability	2013	C	O
59	Towards Automated IoT Application Deployment by a Cloud-Based Approach	2013	C	D
60	Mobile Fog: A Programming Model for Large-Scale Applications on the Internet of Things	2013	C	D
61	Gateway as a service- A cloud computing framework for web of things	2012	C	O
62	Behaviour-Aware Compositions of Things	2012	C	O
63	Knowledge-Aware and Service-Oriented Middleware for deploying	2012	J	B
64	Mashing up the Internet of Things: A framework for smart environments	2012	J	O
65	D-LITE: Distributed logic for internet of things services	2011	C	B
66	Adaptable Service Composition for Very-Large-Scale IoT Systems	2011	W	O
67	INOX: A managed service platform for inter-connected smart objects	2011	W	B
68	Connecting Smart Things through Web Services Orchestrations	2010	W	O
69	COSMOS: a middleware for integrated data processing over heterogeneous sensor networks	2008	J	O

v Venue type: J = Journal (19 papers), C = Conference (37 papers), W = Workshop (13 papers).
f Focus: D = Deployment, O = Orchestration, B = Both Deployment and Orchestration.
* The titles are clickable to link to the corresponding publications

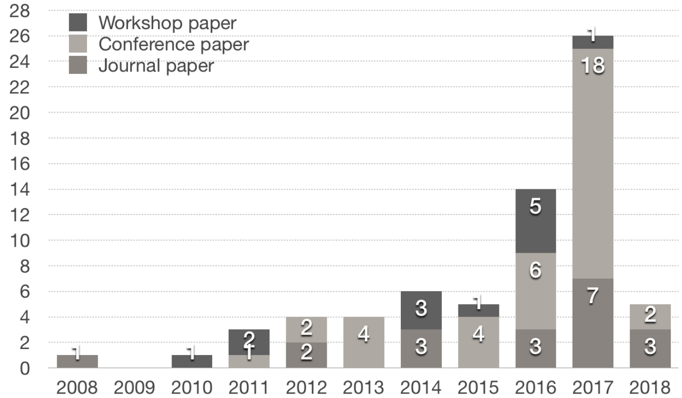

Figure 2: Publications per year, per venue type

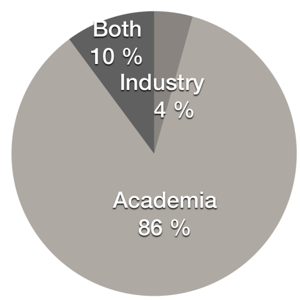

Figure 3: The affiliations of authors

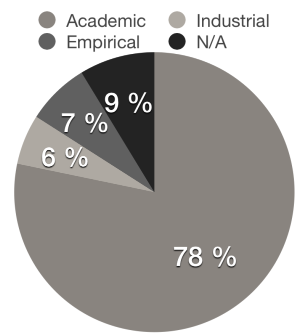

Figure 4: Evaluation case studies

3.2 RQ2: Deployment & Orchestration support

Fig. 5 shows the distribution of primary studies based on the focus: orchestration, or deployment, or both orchestration and deployment. We can see that the orchestration-focused studies are nearly double the deployment-focused studies. The main reason could be that the orchestration-focused studies are around IoT data mash-up at cloud or edge level, which we show later in Fig. 6. It is understandable that the first IoT research focus is more on building IoT applications (orchestration) before deploying them. These studies do not technically contribute to low-level orchestration involving IoT devices or gateways but rather make assumptions on low-level IoT infrastructure. About one-third (37%) of the approaches support both deployment and orchestration. But we would like to note that the degrees of support for deployment and orchestration are not at the same level. In other words, approaches that support deployment somehow also support orchestration (as part of the deployment specifications overlap with orchestration specifications). However, the orchestration support in these cases is often at a higher level of abstraction than the orchestration-focused approaches that offer specific support for orchestration. The former typically manages logical ports (*e.g.*, port 22 should be open for SSH) for setting up the communication channel between the software components to be deployed. The latter is more concerned with the business logic of

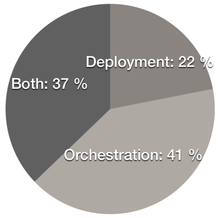

Figure 5: Main focus of the primary Depo4IoT studies

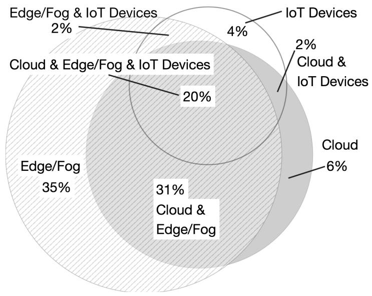

Figure 6: Target infrastructure

an application, and typically manages these interactions at a lower level of abstractions (*e.g.*, remote methods invocation).

Fig. 6 shows how the primary Depo4IoT studies support for different layers of IoT infrastructure: cloud, edge, or IoT devices. Most studies (71%) discuss about mashing up data streaming from IoT devices at cloud (7%) or edge/fog (32%) or both (32%). But, few studies (29%) really support orchestrating and/or deploying software on IoT devices. We would argue that deployment and orchestration at IoT devices are the most challenging research problems in Depo4IoT because of the diversity of IoT devices, their networking protocols and connectivity issues, and their different computing resource constraints. To really support for modern real IoT systems in which trustworthy aspects are crucial, Depo4IoT studies must advance to the technical details of edge devices and IoT devices.

3.3 RQ3: Open issues & proposed research

Even though there is a significant jump in the number of primary Depo4IoT studies recently, our analyses show that Depo4IoT research is still in its infancy. We found that the number of orchestration approaches, often for IoT data mash-up, is nearly double the number of deployment approaches. The orchestration approaches for IoT data mash-up such as the studies numbered 10, 20, 33, 62, 64 in Table 1 often make assumptions of readily deployed IoT systems in operation. IoT deployment approaches should receive more attention. Without proper deployment approaches to deploy IoT systems, orchestration approaches cannot thrive. Besides, it is worth to note that most of the primary Depo4IoT approaches do not really support deployment and/or orchestration at IoT devices, *e.g.*, without technical details about bootstrap or network specification supports. We suggest that future IoT research should dig deep into technical details at IoT devices level to really control the whole chain of IoT software deployed from cloud until IoT devices. In this way, IoT deployment will enable monitoring, adaptation, and actuation conflict management for ensuring the trustworthiness of IoT systems[8]. Finally, the dominance of academia-only in Depo4IoT research suggests that there should be more collaboration between academia and industry to make Depo4IoT approaches more practical and closer to the needs in industry.

4 RELATED WORK

IoT has emerged as an important area of research and development in the recent years. From the software architecture view, an IoT middleware provides a layer between application software and system software. Depo4IoT approaches are not necessary about middleware. Depo4IoT approaches are more vertical along the IoT engineering life-cycle from development to operation of IoT systems. Research on IoT middleware highly overlaps with Depo4IoT because Depo4IoT approaches often leverage middlewares for integrating heterogeneous computing and communications devices, and supporting interoperability within the diverse applications and services running on these devices. In [4] and [6], the authors conducted two different surveys of the existing middlewares to classify them and find out the main challenges. The results of these studies addressed the functional aspects of IoT middleware that we also considered in our work. But, [4, 6] are not systematic studies.

[3] provides a gap analysis on the well-known IoT platforms. In particular, it identifies gaps related security (fine grained access control), cross-platform and cross-layer domain-specific language to reduce threats on privacy and security. The study [3] is not a systematic one and mainly focuses on platforms maturity and usability. [2] is a systematic study on the key IoT architectural concerns. It highlights a set of challenges that is a combination of technical, human, financial and ethical aspects. The study [2] is complementary to our work reported in this paper as [2] does not focus on deployment, orchestration and trustworthiness.

5 CONCLUSIONS AND FUTURE WORK

In this paper, we have examined the research landscape of deployment and orchestration approaches for IoT, by conducting a systematic mapping study. After systematically identifying and reviewing 69 primary studies out of thousands relevant papers in this field, we have found out that 1) there is a sharp rise in the number of publications addressing this field in the two recent years; 2) however, there are still different gaps that the current approaches seem to be immature to address such as the real, low-level technical details of deployment and/or orchestration at IoT devices level; 3) to make the IoT deployment and/or orchestration approaches more practical, there should be more research collaboration between academia and industry. We have been extending this work with more results to be reported in a full mapping study, and a systematic review.

REFERENCES

[1] A. Metzger (Ed.). 2015. Cyber physical systems: Opportunities and challenges for software, services, cloud and data. (2015).
[2] Asif Qumer Gill, Vahid Behbood, Rania Ramadan-Jradi, and Ghassan Beydoun. 2017. IoT architectural concerns: a systematic review. In *Proceedings of the Second International Conference on Internet of things and Cloud Computing*. ACM, 117.
[3] Julien Mineraud, Oleksiy Mazhelis, Xiang Su, and Sasu Tarkoma. 2016. A gap analysis of Internet-of-Things platforms. *Computer Communications* 89 (2016).
[4] Anne H Ngu, Mario Gutierrez, Vangelis Metsis, Surya Nepal, and Quan Z Sheng. 2017. IoT middleware: A survey on issues and enabling technologies. *IEEE Internet of Things Journal* 4, 1 (2017), 1–20.
[5] Kai Petersen, Sairam Vakkalanka, and Ludwik Kuzniarz. 2015. Guidelines for conducting systematic mapping studies in software engineering: An update. *Information and Software Technology* 64 (2015), 1–18.
[6] Mohammad Abdur Razzaque, Marija Milojevic-Jevric, Andrei Palade, and Siobhán Clarke. 2016. Middleware for internet of things: a survey. *IEEE Internet of Things Journal* 3, 1 (2016), 70–95.
[7] Nguyen Khoi Tran, Quan Z Sheng, Muhammad Ali Babar, and Lina Yao. 2017. Searching the Web OF Things: state of the art, challenges, and solutions. *ACM Computing Surveys (CSUR)* 50, 4 (2017), 55.

[8]https://www.enact-project.eu/