An Initial Mapping Study on MDE4IoT

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ABSTRACT

The term "Internet of Things" (IoT) refers to a distributed network of physical objects and applications that create, transform and consume data. Due to the growing interest in digital transformation and Industry 4.0 topics, IoT is becoming more and more important. However, in order to correctly implement IoT concepts that are mostly highly complex, solutions and techniques must be provided to tackle a multitude of challenges such as heterogeneity, collaborative development, reusability of software artifacts, self-adaptation, etc. Model-Driven Engineering (MDE) uses the abstraction power of models to handle the complexity of systems and thus it may act as a key-enabler for IoT systems and applications. Therefore, we present an initial mapping study on the state-of-the-art in the field of MDE4IoT. This study aims to identify to which extent MDE techniques are currently being applied in the field of IoT, and which challenges are addressed.

CCS CONCEPTS

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

KEYWORDS

Model-driven engineering, internet of things, mapping study

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1 INTRODUCTION

The *Internet of Things (IoT)* is the network of physical things and virtual appliances that communicate and interact with each other [4]. The term "things" refers to a wide range of different devices like vehicles, wearable devices, physical sensors (e.g., an embedded air humidity sensor), virtual sensors (e.g., a keystroke analyzer), etc. These things are further interconnected and can exchange data [11], which allows monitoring and controlling devices remotely.

Since embedded hardware (a key enabler for IoT devices) is becoming more affordable, more and more devices are developed and produced every year [12]. Due to the increasing number of devices and complexity of systems, IoT faces different challenges such as (i) heterogeneity [14], (ii) availability of devices [6], (iii) big amount of data [10, 11], (iv) security and privacy [6, 11], etc. Various IoT concepts have emerged in order to tackle some of these challenges, such as the ones listed below:

- Device Description
  During runtime devices execute different operations, sensors provide continuous readings, actuators are triggered and might log their actions in some logging facility. Consequently, a multitude of data is generated. A device description resembles a way to hold metadata to simplify the task of consuming the right data for the right task, and to overcome some forms of heterogeneity as presented in [44]. Beside device information, developers and manufacturer may describe non-functional properties (e.g., energy consumption) which need to be meaningfully represented [12, 42].
- Discovery
  The discovery concept addresses the challenge of availability of devices in an ever-changing environment. For instance, newly added participants can be registered by the discovery of devices and service processes [17, 23]. Yet, easy discovery need to be established in a secure manner, such as to prevent attacks from third parties.
- Deployment
  The deployment concept is the distribution of software components to middleware and hardware. Executable artifacts are deployed to suiting devices. Deployment further deals with the possibility of changing the firmware of things (e.g., in order to provide security patches).
- Self-Adaptation
  Self-adaptation is the power of a system to adapt itself whenever there is a change in the environment. For instance, Ciccozzi and Spalazzese present an example of self-adaptation by a smart street light example [12]. In this example, road users are automatically warned about the speeding of other cars, bikes, or pedestrians by means of lampposts and colored lights. If a lamppost is unfortunately not available, the system must automatically react by self-adaptation in order to guarantee the safety of road users. Another aspect of self-adaptation refers to self-healing properties, i.e., the capability of a device to overcome failure of a sub-component or another connected device that is required for normal operation.
- Service Composition
  IoT devices expose their data and functionality through remotely accessible services and so abstract from the underlying hardware. IoT appliances can consume these services, aggregate input data from various sources and provide new

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information that can in turn be consumed by other appliances or devices. The resulting IoT application represents a "service composition" [41, 42].

- Cloud/Fog/Edge
  Cloud services play typically an important role in IoT environments to consolidate data from various sources and to overcome the limited computational power of embedded devices that operate at the edge of the network. In order to reduce the amount of data sent between edge devices and central cloud services, or to reduce the response time for a given remote call, a hierarchical network might be used in certain cases. Resulting local cloud services resemble the fog of an IoT system. Time-critical data can be processed at the edge of the network (edge computing) and/or using local cloud services (fog computing) [40, 44].
- Middleware
  Middleware aims to hide the heterogeneity of IoT devices and communication protocols in a distributed system and to create a homogeneous interface for interaction purposes [2]. Often, middleware comprises (i) methods to describe the services of devices and (ii) a communication protocol for accessing these services. In a complex IoT application one could easily have to deal with a number of different middleware approaches that need to be understood and supported.

This listing gives a hint on the complexity and diversity of available IoT concepts. One way, amongst others, to handle complexity is the use of *Model-Driven Engineering (MDE)* techniques [8, 37]. MDE follows the principle "everything is a model" for driving the adoption and ensuring the coherence of model-driven techniques [7]. A key principle is to address engineering issues with formal models, i.e., machine-readable and processable representations. Thus, MDE provides a set of advantages for driving an engineering process effectively and efficiently [8]. Thereby, modeling languages, including Domain Specific Languages (DSLs), are used together with techniques like semantic models, code generation, and model transformation to reduce the effort and costs of developing software applications [33]. For instance, through the abstraction power of models the representation of a system can be more human understandable [23, 35]. Models can be aligned to create a global and integrated representation of systems from different viewpoints in order (i) to reason about consistency, (ii) to improve the internal structure without changing the overall behavior, and (iii) to translate them to other formalisms for code generation and simulation [8]. Various modeling environments offer tool support for these tasks, which can be adapted to the used modeling language.

The overall goal of this mapping study is to get an initial insight how and which IoT concepts are used in combination with MDE. The remainder of the paper is structured as follows. Section 2 discusses related work. Section 3 presents our research method, the defined research questions, and the screening process. In Section 4 the extracted data is analyzed and the results are visualized. Section 5 presents the conclusion and an outlook for future work.

2 RELATED WORK

In this section, we discuss systematic literature reviews (SLR) dealing with MDE approaches in combination with the aforementioned concepts such as cloud computing, self-adaptation, service composition, etc. The following discussed SLRs give an overview of related works in this direction without the claim of completeness.

In [32], the authors investigate the application of MDE approaches and techniques in cloud computing. They were firstly interested in the extent to which MDE is an effective development approach for cloud computing, and secondly on cloud computing tools which were developed by applying MDE techniques. In this context, they identified 25 research works originated during 2009–2016. They classified these works and related them to three different layers, which are Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS). Roughly summarized, MDE techniques are mostly applied on cloud applications at the SaaS layer.

Often in literature the term "Cyber-Physical Systems (CPS)" is used synonymously or closely related to IoT. Therefore, we point to an SLR, presented by [31], which examines the concept of self-adaptation in the domain of CPS. The authors report about a number of studies using self-adaptation features in the engineering of CPS. In our initial mapping survey, we also consider self-adaptation as an IoT-concept, amongst others. Muccini et al. found out that self-adaptation is a cross-layer concern, where engineering solutions combine different adaptation mechanisms within as well as across layers. Furthermore, the main concerns for self-adaptation are performance, flexibility, and reliability.

An SLR in the domain of smart homes is delivered by [18]. The survey analyzes tools for supporting end-user development for smart home configuration and management. The investigated tools have rule-based behavior definitions and visual interfaces, and they are made for users without experience in software development. However, since MDE has no matter of importance in this SLR it is unclear whether MDE techniques have been applied when developing these tools, or not.

A related field to IoT are embedded systems, so we refer to another SLR presented by [38]. This SLR do not explicitly consider IoT and its concepts, but MDE techniques. The objective of this SLR was to identify current features of the usage of choreography in the domain of embedded systems. The SLR indicates that choreography is seen as a solution for problems caused by technical as well as technological heterogeneity, which are challenging problems in the IoT domain. The authors found out that middleware is the context in which choreography is most frequently studied and that MDE techniques are frequently used for adaptation strategy.

Another SLR that takes MDE and service choreography adaptation into account is delivered by [28]. The authors classified 24 relevant existing studies in six categories based on the studies' investigated topics which were: model-based, measurement-based, multi-agent-based, formal-based, semantic reasoning-based, and proxy layer approaches. Based on this classification, the authors present a detailed summary of the state-of-the-art of service choreography adaptation.

The main difference between the discussed SLRs to our initial mapping study is that the presented ones are focusing on a single IoT topic like cloud computing, self-adaptation, or service composition in combination with MDE techniques. In contrast, we are taking more than one topic into account when investigating MDE4IoT.

3 METHODOLOGY

This section gives an overview of the search and screening process of our initial mapping study. We firstly define our research questions, and then conduct the search process by Google Scholar[1]. Additionally, we use the snowballing method introduced in [43] in order to find additional papers for our research scope. The procedure of our initial study is oriented towards the guidelines for systematic literature reviews [5] and systematic mapping studies [34].

3.1 Research Questions

The research questions to be addressed are as follows:

- **RQ 1**: *Which IoT concepts are tackled by MDE4IoT approaches?*
- **RQ 2**: *Which MDE approaches/techniques are used to solve the challenges of IoT?*

The main aim of this initial survey is to find out to which extent MDE techniques are currently being applied in the field of IoT. In addition, we investigate which of the previously introduced challenges (cf. Section 1) are tackled by MDE approaches.

3.2 Search Process

We use Google Scholar for conducting our search process. The accepted languages of publications for our result set were restricted to English and German. We made no restrictions for publication date. We settled on the following search query:

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(‘‘model driven engineering’’ OR MDE OR ‘‘model based’’
OR ‘‘model driven’’)(‘‘internet of things’’ OR IoT)
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Using this query, we were not focusing on specific IoT concepts or MDE techniques, since our aim was to find publications with a high relevance of, both IoT and MDE. Therefore, we selected whole phrases (quotation mark) and not single words (except for abbreviations). As output we got 18.400 results. In a next step, we sorted the papers by date (newest first) and by relevance. Based on Google Scholar, "relevance" in our survey means to take the number of occurrences of the search terms within a paper into account.

For further investigations, we used the 22 most relevant papers and the 15 most recent ones. Additionally, the 15 most quoted papers were selected. Since Google Scholar cannot sort papers according to the number of quotations, we looked through the first 500 publications manually. In a next step, we checked these 52 publications and filtered out all papers that had no reference to MDE or IoT. After this filtering, 22 papers remained in the result set. As mentioned before, we also used snowballing to get high relevant papers in the scope of IoT and MDE. For this purpose, we checked the references of the result set and found 24 additional papers in our field of interest. Finally, our result set covers 46 documents: 22 from Google Scholar search and 24 from snowballing process. 3 publications of these 46 are project deliverables, and 43 are scientific conference papers and articles.

[1] https://scholar.google.at/

4 MAPPING OF PAPERS

In this section, we describe analysis and results to answer the research questions (RQ 1 and RQ 2). For analyzing and classifying the publications of our result set, we primarily used the abstract and conclusion of a paper. If an assignment based on these two parts was not possible, the approach of the paper has been read. Whenever we were not able to do an assignment of a paper to one of the IoT concepts and/or the defined MDE techniques, we excluded it from our analysis. After this additional screening process, 26 of 46 publications remained in our result set.

4.1 RQ 1: Which IoT concepts are tackled by MDE4IoT approaches?

To answer this first research question, we started by analyzing the covered IoT concepts of the publications in the result set. For this purpose we checked and classified them regarding the used IoT concepts (cf. Section 1) in order to deal with IoT challenges. Table 1 shows the utilised IoT concepts and the assigned publications. The ordering is done by the numbers of publications assigned to an IoT concept (i.e., we have done an occurrence count).

Table 1: Distribution of publications by IoT concepts

Concept	Count	Publications
Service Composition	15	[3], [6], [13], [15], [20], [21], [22], [24], [25], [26], [27], [29], [39], [40], [41], [42]
Discovery	11	[1], [3], [6], [9], [11], [13], [24], [25], [36], [42], [44]
Device Description	10	[3], [6], [12], [13], [23], [30], [33], [36], [42], [44]
Middleware	8	[13], [16], [22], [25], [27], [29], [33], [44]
Cloud/Fog/Edge	7	[1], [9], [19], [22], [36], [40], [44]
Deployment	6	[6], [11], [16], [24], [27], [33]
Self-Adaptation	4	[11], [12], [29], [42]

We found out that most of the listed publications cover more than a single IoT concept. One of the reasons is that IoT concepts usually work together to successfully solve open challenges, therefore the introduced approaches serve several concepts. The papers [13, 42, 44] cover at least 4 different IoT concepts. The presented approach in [13] presents a model-driven development toolkit for industrial applications. The authors of [42] show a design of a comprehensive description ontology for IoT knowledge representation and in [44] an architecture for massive IoT is presented. These three publications examine IoT in a larger context, and therefore several concepts were addressed.

An additional remarkable aspect is that all mentioned IoT concepts (cf. Section 1) are applied in the research field of MDE4IoT. This proves that the advantages of MDE are taken in different IoT fields. Many papers of the result set used Web services such as SOAP and especially RESTful Web services to expose the functions and data of IoT devices. There is also a project focusing the MDE4IoT area. This project named BIG IoT [3, 9, 24, 36] tries to tackle the challenges by building an ecosystem over multiple platforms. The goal of the BIG IoT framework is to support the transformation from an offering description representation to a W3C Thing description representation [24].

4.2 RQ 2: Which MDE approaches/techniques are used to solve the challenges of IoT?

For answering the second research question, we analyzed the publications on the basis of the used MDE techniques. Based on this, we differ the following techniques which tackle various IoT challenges:

- Semantic Model/Meta Model: This category includes all approaches that use the concept of metamodeling.
- Code Generation: This category includes all approaches that contain the automatic generation of source code in a specific programming language.
- DSL/DSML: This technique describes the approaches where a domain-specific language was developed.
- Model Transformation: This category includes all publications that use model transformations (transformation from source to target models).
- UML Profile: This category is used for publications whose approach presents its own UML profile.
- Specific Framework: All approaches in this category work on specific model-based implemented frameworks.

Based on the listed MDE techniques, we classified the selected and filtered publications. Table 2 shows the MDE techniques and assigned publications. The scientific papers of [12, 15] introduce MDE4IoT frameworks covering more than only a single MDE technique. In contrast to the other publications, these two papers cover in total 4 different techniques. The IoT-A deliverable [6] is the only publication of our result set where the interaction of a user with a device is modeled. In this context, the user can be a human or a digital entity, such as a service. Furthermore, the approach introduced in [15] uses already IoT-A in the Papyrus[2] for IoT modeling environment.

Table 2: Distribution of publications by MDE techniques

Technique	Count	Publication
Semantic Model/Meta Model	17	[3], [6], [9], [11], [13], [15], [16], [23], [24], [25], [26], [29], [30], [36], [39], [41], [42]
Specific Framework	13	[1], [12], [15], [19], [20], [22], [23], [24], [25], [30], [33], [39], [40]
Code Generation	5	[12], [15], [33], [40], [41]
DSL/DSML	5	[11], [21], [27], [33], [44]
Model Transformation	3	[12], [15], [39]
UML Profile	2	[12], [40]

It is worth to mention that many different modeling tools, languages as well as frameworks were applied in the selected and filtered publications. The following list gives an overview of this diversity:

- EMF - Eclipse Modeling Framework[3]
- Xtext[4]
- MOF - Meta Object Facility[5]
- SysML - Systems Modeling Language[6]
- BIP - Behavior-Interaction-Priority[7]
- IoTML - IoT Modeling Language[8]
- MIM - Model Integrated Mechatronics[9]
- Srijan Languages[10]
- ThingML[11]
- UML4IoT[12]
- MDE4IoT [12]
- Sm@rt - Supporting Models at Run-Time[13]
- DDL - Device Description Language[14]
- MARTE[15]

4.3 Synopsis

Based on the classification of our result set it is now possible to link IoT concepts with MDE techniques to an initial MDE4IoT map (cf. Fig. 1). To put it in a nutshell, the most common combination is semantic model/meta model with service composition. This combination results from the fact that most approaches describe an architecture for IoT as semantic model / metamodel where both metadata and non-functional requirements are comprehensibly mapped.

5 CONCLUSION AND OUTLOOK

In this initial mapping study on MDE4IoT, we investigated (i) to which extent MDE techniques are currently being applied in the field of IoT, and (ii) which MDE approaches/techniques are used to solve the challenges of IoT. We used Google Scholar and snowballing to search for publications in the field of MDE4Iot and got 26 publications for our result set. We found out that the IoT concepts such as service composition, discovery, deployment, device description, middleware, cloud/fog/edge and self-adaptation are all used in that area to solve IoT challenges (e.g., heterogeneity). In concrete numbers this means that the most addressed IoT concept is service composition with 16 occurrences followed by discovery (11 occurrences), device description (10 occurrences), middleware

[2] https://www.eclipse.org/community/eclipse_newsletter/2016/april/article3.php
[3] https://www.eclipse.org/modeling/emf/
[4] http://www.eclipse.org/Xtext/
[5] https://www.omg.org/mof/
[6] http://www.omgsysml.org
[7] http://www-verimag.imag.fr/Rigorous-Design-of-Component-Based.html
[8] https://git.eclipse.org/c/papyrus/org.eclipse.papyrus-iotml.git
[9] http://seg.ece.upatras.gr/MIM/
[10] https://github.com/pankeshlinux/IoTSuite/wiki/Specifying_Domain_Vocabulary
[11] http://thingml.org/
[12] https://sites.google.com/site/uml4iot/
[13] http://code.google.com/p/smatrt/
[14] https://www.cise.ufl.edu/~helal/opensource.htm
[15] https://www.omg.org/omgmarte/

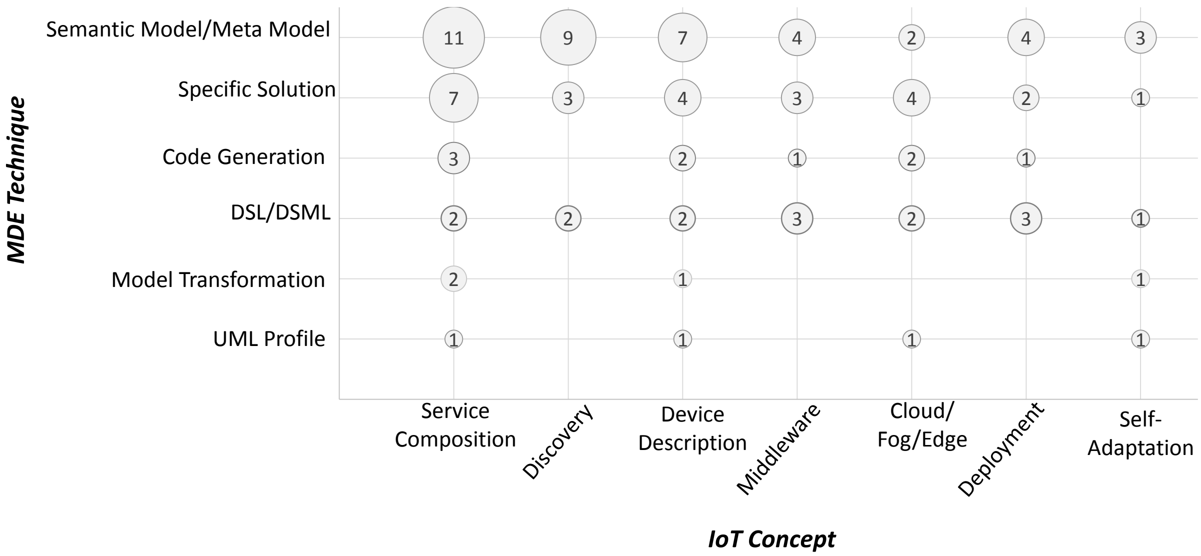

Figure 1: Map of MDE techniques with IoT concepts

(8 occurrences), cloud/fog/edge (7 occurrences), deployment (6 occurrences), and self-adaptation (4 occurrences).

For answering our second research question (cf. Section 4.2), we found out that the most occurring MDE technique in our result set is semantic model/meta model with 17 occurrences, followed by specific framework (13 occurrences), code generation (5 occurrences), DSL/DSML (5 occurrences), model transformation (3 occurrences), and UML profile with an occurrence of 2.

Additionally, we investigated which of these techniques occur with which IoT concept in the same paper. We found out that the most frequent combination is semantic model/meta model (MDE technique) with service composition (IoT concept).

We further found out that in many scientific papers RESTful Web services were applied to expose the functions and data of IoT devices, and most frequently used MDE frameworks are DDL, ThingML, MDE4IoT, UML4IoT, and EMF.

Regarding the presented initial mapping study, we foresee the following next steps. First of all, we plan to expand the used digital libraries for the search process. We just used Google Scholar but there are many other digital literature libraries available on the Web such as Scopus[16], ACM[17], and IEEE Xplore[18]. Thus, in this extended search scope additional filtering criteria are offered by these libraries that can be used for a better screening process. Second, we plan to extend this mapping study to a systematic literature review in order to enable a more precise analysis and a more detailed synthesis.

From a content-wise perspective, it should be examined whether MDE4IoT has effects on existing modeling languages, or not. For example, is it necessary to expand CloudML[19] for IoT or can this language be used directly for modeling IoT concepts? The general question is, whether we need a domain specific language for a domain such as IIoT, or whether general purpose languages are sufficient to describe the IoT domain.

[16]https://www.scopus.com
[17]https://dl.acm.org/
[18]https://ieeexplore.ieee.org/Xplore/home.jsp
[19]https://cloud.google.com/ml-engine/

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