Internet-of-Things Marketplaces: State-of-the-Art and the Role of Distributed Ledger Technology

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Abstract. The advent of the Internet-of-Things (IoT) generates increasing data with the majority being gathered for a single purpose and staying unused after serving this purpose. With IoT platforms, cross-domain use cases, combining data from different sources, become possible. Accordingly, the need for marketplaces to trade data arises. This paper examines existing IoT platforms to frame the current opportunities for an IoT marketplace. In a second step, it analyzes the potentials of Distributed Ledger Technology (DLT) regarding transaction costs and efficiencies. In doing so, a classification regarding the functional distribution of IoT marketplaces is developed.

Keywords: Internet-of-Things (IoT) · Platform · Marketplace · Distributed Ledger Technology (DLT) · Blockchain

1 Introduction

1.1 Motivation

The Internet-of-Things (IoT) is defined as the interlinking of devices connected via a network to collect and exchange data. Currently, a variety of such devices (e.g., sensors) measure various attributes and produce an amount of data every day [1]. The quick deployment of IoT devices will lead to more than 20 billion connected devices gathering data by 2020 [2]. All this data is mostly stored in so-called 'data silos'. A data silo is characterized by a closed environment with little to no sharing with outside environments, and thus, data does not contribute to any additional revenue streams for its creator. The data usually leave the silo once only to be transferred to an IoT platform for analysis and visualization for a single purpose [3]. The idea of a cross-domain data scenario is the combination of data from different single-purpose data silos to achieve value by serving an additional purpose in an additional context. The consideration of external, non-domain data promises an optimization of forecasts and an improvement of decisions [4].

For this paper, nine semi-structured interviews with CEOs, managing directors, one head of sales, one head of product management, and one consultant of small and midsize

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companies (SMC) from different branches in Germany were conducted. The interview procedure follows an unstructured interview guideline. It provides an introduction to the cross-domain data approach and its goals, according to Bär et al. [4]. It is followed by the question of whether cross-domain data projects are currently being conducted in a particular company or have already been carried out in the past? Since this question was answered in the negative in all interviews, it was followed by a survey on the reasons for these obstacles.

Although all SMCs believe cross-domain data scenarios have promising potential for their own company, none of the companies already have or had in the past a cross-domain data project. The obstacles mentioned by the interviewees are synthesized and may be organized in the following clusters: technological, economic, organizational, and legal. This paper adopts a technological and partly an economic perspective. Thus, the main questions for SMCs in these clusters are: Where is data from external domains offered? At what price is this data offered? Where are the essential analytic and presentation services offered and at which price?

One possible solution for answering these challenges is an IoT platform that offers data for sale via an integrated data marketplace [5]. Such an IoT data marketplace follows the concept of electronic marketplaces by Schmid and Lindemann [6] where data vendors from different sources and branches offer their data. Buyers of data pay the vendor and acquire the data set or data stream [7]. However, data is not the only conceivable commodity on IoT marketplaces. Services for the analysis and visualization of data could also potentially be made available via such a marketplace by various participants. Especially for complex cross-domain use cases that require multiple data from different vendors and branches as well as different analytic functionalities, an IoT marketplace would become relevant [4]. The hypothesis is that this approach – opening those data silos and trading the data – enables the creation of new business models.

The fact that the Distributed Ledger Technology (DLT) is suitable for electronic markets as an underlying technology, is acknowledged in the literature (e.g., [8, 9]). Especially the combination of DLT and IoT marketplaces holds great potential for innovation [7, 10, 11]. DLT enables micropayments and serves as a 'tool' for handling transactions on an IoT marketplace. In addition, DLT facilitates the use of smart contracts, enabling the autonomous checking of predefined events and the automatic execution of transactions. Thus, a smart contract can autonomously control, monitor, and document actions depending on digitally verifiable events. Based on the DLT, an information and value transfer (e.g., between data vendor and data purchaser) could be designed efficiently without the need for an intermediary [12]. A DLT-based platform not only promises to minimize the risk of vendor lock-ins and monopolization but also to reduce transaction costs for its users [13].

1.2 Methodology

The overall aim of this paper is to advance the understanding of the technical tools with which cross-domain data projects can be carried out in companies and which economic potentials can be realized. Figure 1 summarizes the research methodology in this paper. In the first step, the key IoT platform functionalities are identified by a scientific literature search, according to vom Brocke et al. [14]. These key functionalities are used in a second step to conduct an online market examination, according to Hileman and Rauchs [15], to provide an impression of traditional as well as DLT-based IoT platform solutions currently available on the market. Building on an established electronic market model by [6] and the dimensions of digital platforms by Blaschke et al. [16], a classification of the functional distribution of IoT marketplaces is developed. Subsequently, it is used to analyze the opportunities for synergies of IoT marketplaces and DLT as a potential enabling technology for some of the key functionalities. Thereby the paper highlights the suitability of the DLT to create value for such an IoT marketplace.

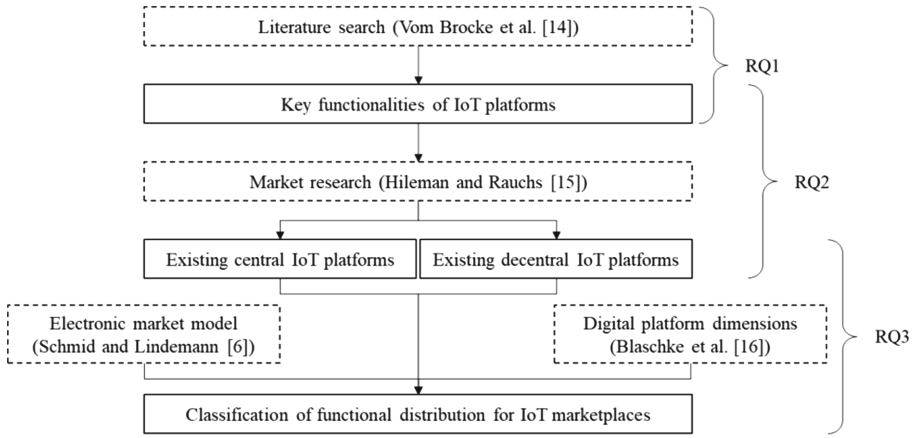

Fig. 1. Research methodology.

Three research questions (RQ) shall be formulated: (RQ1) What are the key functionalities of IoT platforms? (RQ2) Which IoT platform solutions, using which of these functionalities, currently exist for companies to carry out cross-domain IoT data projects? (RQ3) How can the functional distribution of IoT marketplaces be conceptually delineated for analyzing the potential of DLT?

The remainder of this paper is structured as follows. In Sect. 2, a brief overview of the terms IoT platform, IoT marketplace, and DLT, is presented. A literature review is conducted in Sect. 3 to identify the key functionalities of IoT platforms. The state-of-the-art based on the market examination in traditional and DLT-based IoT platforms is outlined in Sect. 4. The developed classification for the functional distribution of IoT marketplaces is presented in Sect. 5. Finally, a brief conclusion, limitations, and further research lines are provided in the last section.

2 Foundations

2.1 Internet-of-Things, IoT Platform, and IoT Marketplace

The Internet-of-Things (IoT) enables 'things' in terms of devices like sensors and everyday items, typically not considered as computers to become active participants in business, information, and social processes. This facilitates devices to generate data for communicating or interacting among themselves and with its environment independently [4].

However, the capacity of IoT devices is typically limited. Therefore, the storage and processing of the captured data are usually not taking place within the device. In a generic IoT infrastructure, the device itself is only a minor part of the IoT landscape [17]. The significant part in which data converges and the generation of added value occurs is the so-called IoT platform [18].

Gawer [19] describes platforms as foundational products, services, or technologies serving as a basis for developing supplementary products, services, or technologies. In the case of an IoT platform, it handles different hardware and software communication and authentication protocols for IoT devices and users. The primary purpose of IoT platforms may be summarized as gathering, analyzing, and visualizing data [4]. Further, an electronic platform may be seen as an electronic market, focusing on the coordination of multiple participants that aim to interact with each other [20]. Schmid and Lindemann [6] developed a reference model and elaborated two key functionalities for electronic markets: (1) Nodes are linking multiple participants, e.g., producers or vendors that offer services or products to customers. (2) An infrastructure, used for offering services and products [6, 21]. This is in accordance with the four layers of digital platforms: the digital infrastructure, the technical platform core, the ecosystem (containing the participants), and the service dimension [16]. These layers are transferable to IoT marketplaces since platform businesses by nature are intermediaries on an electronic marketplace [20]. Traditionally, there is one owner as the central provider of a platform or rather a marketplace. The platform owner is responsible for providing access to the platform (e.g., via web), governing the platform (e.g., user registration), and offering coordination tools on the platform (e.g., directories) [22]. Besides providing these basic platform services, the owner decides whether other services (e.g., analytic functionalities) are offered exclusively by the owner or also by third providers [6, 23]. In addition, data may be traded on such an electronic market. Due to the fact, every electronic marketplace is a platform, but not every platform is an electronic marketplace [20], the following refers to an IoT platform with an integrated marketplace as an IoT marketplace.

2.2 Distributed Ledger Technology

DLT describes a distributed and digital ledger that is built on a peer-to-peer (P2P)-network of independent nodes. Upon this ledger, transaction information of digital assets or digital values is immutably grouped into transaction sets. These sets are cryptographically linked to the previous transaction sets by a consensus mechanism. Leading to a chronological ordering of all transactions. As the transactions are immutable, they cannot be altered or deleted afterward – only new transactions may be added. Finally, the ledger is shared and synchronized among all nodes of the P2P-network, which increases the fault tolerance of the entire ledger [11, 24, 25].

The specifics of storing data and processing transactions in a DLT generates challenges in the IoT context [1], such as confidentiality, autonomous behavior and fault tolerance [7, 10, 26]. DLT enables the automation of complete or partial processes and services and thus improves the coordination among electronic markets. Moreover, the decentralized nature of DLT empowers the individual users by allowing them more control of data. The consolidation of data located within a network of different actors is achieved by DLT while offering properties to avoid vendor lock-ins at the same time

[8, 25]. In conclusion, the technology may advance the generic advantages of electronic markets [21] towards autonomously managed multi-sided electronic marketplaces [9].

3 Functionalities of IoT Platforms

3.1 Literature Review

Using the systematic literature search according to [14], the current state of research on reference architectures and key functionalities of IoT marketplaces and platforms, as well as possible DLT-based solutions, will be elaborated. First, the scope of the review is defined, and the conceptualization of the topic is elaborated. Based on this, the following search term pairs in English and German are derived for obtaining comprehensive and relevant search results: The first pair is 'IoT platform' and 'IoT marketplace' and the second pair is 'functionality' and 'feature'. For identifying relevant literature, common scientific databases (AIS eLibary, EBSCOhost, IEEE Xplore, and Springer Link) are searched for journals and conference proceedings with a peer-review procedure. The mentioned keywords are used in various combinations for the full-text search, and only German and English literature is considered. To adequately reflect the continuous developments in the field of IoT and DLT, the literature review is extended by a forward and backward search, according to [14]. This search procedure is based on further relevant publications of the authors as well as on the sources used in the articles found. Publications without a peer-review procedure are also considered here to elaborate on the latest state. After the literature search for each database and after removing duplicates, a set of 41 selected papers is analyzed. In total, 11 relevant papers are identified, which are used for synthesizing key functionalities of IoT platforms in the following.

3.2 Synthesized Functionalities

Based on the conducted literature review, various proposals for overviews of functionalities of IoT platforms (e.g., [1, 3]) could be found. Although the platforms are partly equipped with similar functionalities, there are different technological approaches and terminologies [27]. However, the descriptions of these functionalities in the literature partly focus on single functionalities in detail. As shown in Table 1, key functionalities of IoT platforms have been synthesized from the literature to compensate these shortcomings. They will be used in the following examination of this paper.

Apart from the basic platform services mentioned in 2.1 (access, governance, and coordination, which are provided as cross-layer functionalities), these key functionalities are:

1. Connectivity: Includes identification management and dedicated device management, supporting users to deploy and configure heterogeneous IoT devices for collecting data [3, 28].
2. Data Storage: Data may be stored at a cloud server provided by the platform provider, on local databases/servers by the user or via an internal interface on a dedicated DLT infrastructure [7, 27].

3. Marketplace: A platform-integrated marketplace for data, analytics, or presentation services of third-party service providers [6, 20].
4. Analytics: Tools including edge analytics and machine learning skills, like cognitive, anomaly, and predictive analytics capabilities to extract insights from IoT data [28, 29]. Edge analytic describes a first simple data analysis taking place at the point of gathering (e.g., sensor device). After that, only a pre-selection of the data is transferred to the platform for further analysis [17]. Cognitive analytics include capabilities like natural language processing, text mining, or video and image recognition [29]. Anomaly or stream analytics describes a low latency analysis in real-time for anomaly detection [28]. Predictive analytics generate forecasts using historical data. In particular, this is also available in real-time [30].
5. Presentation: Empowers to create and deploy an IoT application or smart service rapidly. Another form are visualizations, e.g., dashboards, diagrams, or graphs [4, 27].

Table 1. Overview of IoT platform key functionalities

Functionality	**Functionality characteristics**			
Presentation	Visualization	Smart service	IoT application	
Analytics	Edge	Cognitive	Anomaly	Predictive
Marketplace	Data	Analytic functionality as a service	Presentation functionality as a service	
Data storage	Local database	Cloud server	Distributed ledger	
Connectivity	Device management	Deployment configuration	Identification management	

4 State-of-the-Art in IoT Platforms

The previous literature search identified papers that focused on individual platforms (e.g., IBM Watson IoT), on certain IoT platform aspects (e.g., edge analytics [17]) or on individual use cases, but not on the overall structure of IoT platform concepts. To obtain this information, an online market research to identify current IoT platform solutions is conducted according to [15]. To identify smaller IoT platform or IoT marketplace projects, a search for whitepapers, technical documentations, and postings in non-scientific media like branch-specific websites (e.g., cryptoslate.com) or blogs (e.g., medium.com) was conducted. The key functionalities and its characteristics elaborated in Table 1 serve as the underlying research design for the market research. From an architectural perspective, there are two types of IoT platform solutions – centralized and decentralized – which are examined in the market research separately.

4.1 Traditional IoT Platforms as Centralized Solutions

A variety of different IoT platforms have been created for a wide range of use cases by open source communities (e.g., FIWARE, OpenMTC) as well as commercial companies (e.g., IBM, Siemens). This analysis is limited to commercial providers for serving better comparability. Table 2 summarizes the key functionalities for selected commercial IoT platforms available on the market. Since the field of IoT is quite complex and fast-moving, it cannot be excluded that individual IoT platforms either are missing or are outdated yet. The set of examined IoT platforms in this paper has to be considered as a snapshot of current market insights.

Table 2. Comparison of traditional IoT platforms currently available on the market

Platform name	Connectivity	Data storage location: Serial interface to DLT	Data storage location: Cloud-server	Data storage location: Local database	Marketplace	Edge analytics	Machine Learning: Cognitive analytics	Machine Learning: Anomaly analytics	Machine Learning: Predictive analytics	Presentation functionalities
Atos Codex IoT	●	○	●	●	○	○	○	○	●	○
AWS IoT Core	●	○	●	○	○	●	●	●	●	●
Bosch IoT Suite	●	○	●	○	○	○	○	●	○	●
Cumulocity IoT	●	○	●	●	○	●	○	●	●	●
GE Predix	●	○	●	○	○	●	○	●	●	●
Google IoT Core	●	○	●	○	○	●	●	●	●	●
HPE Universal IoT	●	○	●	●	○	●	○	●	●	●
IBM Watson IoT	●	Hyperledger	●	●	○	●	●	●	●	●
Microsoft Azure IoT	●	Azure Blockchain	●	●	○	●	○	●	●	●
Oracle IoT Cloud	●	○	●	○	○	○	○	●	●	●
PTC ThingWorx	●	○	●	●	○	○	○	●	●	●
Relayr IoT Middleware	●	○	●	●	○	●	○	●	●	●
SalesForce IoT	●	○	●	○	○	○	●	●	●	●
SAP Leonardo IoT	●	Hyperledger Fabric, MultiChain, Quorum	●	●	○	●	○	●	●	●
Siemens MindSphere	●	○	●	●	●[A]	●*	●*	●*	●*	●

● - yes | ○ - no | [A] - Analytics services | * only in combination with AWS or Azure services

All examined platforms provide connectivity functionality, and all but one platform offer presentation functionalities. Both seem to be standard functionalities of traditional IoT platforms. This is possibly since these functionalities affecting the end-user directly and, therefore, are suitable sales arguments. The analytic functionalities are partly given. Only Siemens MindSphere offers the possibility to use third-party analytic functionalities. However, as MindSphere lacks in-house analytic functionalities, it offers AWS and Microsoft Azure services. None of the further platforms examined feature an integrated marketplace. Moreover, all platforms relied on data storage in the cloud, and three providers even had a serial interface to a DLT framework – namely IBM Watson with Hyperledger, Microsoft Azure with the Ethereum-based Azure Blockchain and SAP Leonardo with Hyperledger Fabric, MultiChain or Quorum.

Overall, the key functionalities suggested in this paper may be regarded as provisionally validated in order to accurately map and compare available IoT platform solutions in their functionalities.

4.2 DLT-Based IoT Platforms as Decentralized Solutions

The majority of the reviewed traditional platforms rely on conventional database architectures and are centralized operated by one provider. This evokes the question of whether a market of IoT platforms using DLT and pursuing functional distribution is already existing. Two main fields of application may be distinguished for DLT: First, it is used for processing purchase transactions on the IoT marketplaces and the autonomous operation of this marketplace. Second, it may be used for data verification and storage. Accordingly, the key functionalities in Table 1 may also be applied to DLT-based platforms, with a small change by introducing the distinction between on-chain and off-chain data storage locations. There are two ways to connect or integrate IoT platforms with DLT. (1) As mentioned above, a distributed ledger is integrated into a traditional IoT platform via a serial interface, e.g., IBM Watson with Hyperledger. (2) Another solution is a standalone DLT framework providing a completely DLT-based IoT platform, e.g., IOTA.

Although a small number of IoT platforms already implement DLT as the underlying architecture, this industry is continuously progressing. These platforms partly address specific niches, e.g., some operate open platforms for storing, sharing, and trading sensor data [10]. Table 3 gives an impression of a sample of commercial DLT-based IoT platforms currently available. Since it is a fast-moving and fast-developing industry, this may only be seen as a current snapshot of market insights without claiming completeness.

It may be viewed that DLT-based IoT platforms offer more often the possibility of marketplaces, while analytic and presentation functionalities are less often represented compared to traditional platforms. Mainly the marketplaces are used for trading data. Streamr additionally offers presentation functionalities as a service in the form of a visualization dashboard on its marketplace. Analytic services are not offered as a service on a marketplace within the examined platforms. All IoT marketplaces used DLT for processing purchase transactions. IOTA and Datum are the only IoT platforms that offer the possibility of on-chain storage of the sensor data. The remainder of the platforms examined uses DLT to store markers or hashes for verifying the sensor data. An initial validation of the elaborated functionalities in Table 1 may be assumed by this market examination, as all the solutions examined are appropriately described.

Table 3. Comparison of DLT-based IoT platforms currently available on the market

Platform name	Connectivity	DLT framework	Data storage location: On-chain	Data storage location: Off-chain: Cloud-server	Data storage location: Off-chain: Local database	Marketplace	Edge analytics	Machine Learning: Cognitive analytics	Machine Learning: Anomaly analytics	Machine Learning: Predictive analytics	Presentation functionalities
Atonomi	●	Ethereum	○	●	●	●[D]	●	●	●	○	○
Cyber Physical Chain	○	Ethereum	○	●	●	●[D]	○	●	●	●	○
Databroker	○	Ethereum	○	●	●	●[D]	○	○	○	○	○
Datum	●	Ethereum	●	●	●	●[D]	○	○	○	○	○
Flowchain	●	Ethereum	○	●	●	○	○	○	○	○	○
IOTA	●	IOTA	●	●	●	●[D]	○	○	○	○	●
Machine eXchange Coin	●	Ethereum	○	●	●	●[D]	○	○	○	○	○
Orbis Mesh	●	NEO	○	●	●	○	○	○	○	○	●
SDChain	○	Ethereum	○	●	●	●[D]	○	○	○	○	●
Streamr	●	Ethereum	○	●	●	●[D, P]	○	●	●	●	●
Weeve	●	Ethereum, Hyper-ledger, IOTA	○	●	●	●[D]	○	●	●	○	●
XBR Network	○	Ethereum	○	●	●	●[D]	○	○	○	○	○

● - yes | ○ - no | [D] - Data | [P] - Presentation services

5 Classifying Functional Distribution

Based on the electronic market reference model [6], the architecture dimensions of digital platforms [16], and the setting of IoT cross-domain scenarios [4], the typical pipeline of a multi-sided IoT marketplace for a cross-domain sensor data scenario is shown in Fig. 2.

It starts with generating and gathering sensor data. By using the connectivity functionality, a sensor owner records its sensor and transfers it on the IoT platform. First, a pre-processing or filtering of the sensor data is executed. After that step, the prepared data is forwarded to a specific storage location, and the sensor owner, as an end-user, can do both, use its data for own purposes and offer it on the platform-integrated marketplace. Service providers can also offer analytic and presentation functionalities as a service on the marketplace. As an end-user, a customer or smart service may obtain both data and functionality services on the marketplace and, therefore, within the platform. The advantage for both service providers and customers is the fact that the functionality service is offered at the point where the actual need of the customer arises. Each participant interacting on the platform uses the basic platform services.

Functional distribution is possible in this outlined scenario in analogy to other fields such as business process outsourcing [31], enterprise resource planning systems [32], or service lifecycle management [33]. Functional distribution in the context of IoT marketplaces denotes single functionalities that may be distributed horizontally or vertically.

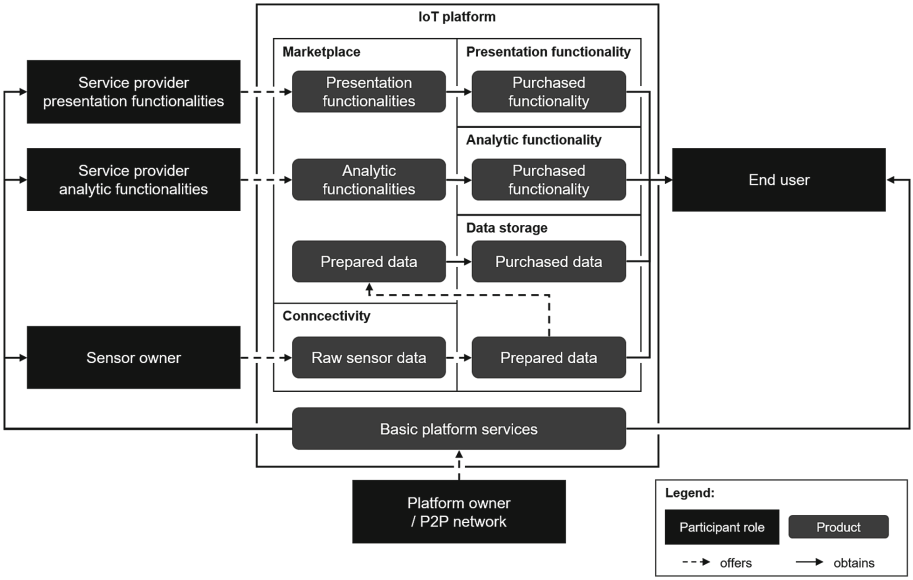

Fig. 2. The setting of an IoT marketplace with roles and products

Thus, they are either provided by a central hierarchical party or by one or more external parties. Basic platform services may also be considered in the functional distribution.

Building on the results of this paper so far enables to create a morphological box for classifying the functional distribution of different IoT platform architectures (see Table 4). Depending on the degree of functional distribution, two elementary business models and hence, two basic architecture designs exist for an IoT marketplace. As mentioned above, a platform may be designed either centralized or decentralized. Based on the results of this paper, three additional subcategories can be identified for IoT platforms: Traditional IoT platforms, IoT platforms with a serial interface to a distributed ledger, and DLT-based IoT platforms. In a centralized architecture, the provider assumes all processes – namely basic platform services, operation of the marketplace, and offering analytics and presentation services. In a decentralized architecture, the provider obtains at least some services by external providers or is entirely obsolete due to external providers or the usage of DLT. Basic platform services and the operation of the marketplace may be distributed via the P2P-network by using DLT. Transactions are processed by using smart contracts, which automate payment processing, data verification, and releasing access to data and services. A trusted third-party is no longer necessary in a fully decentralized IoT platform. Except for providing basic platform services, each participant can take every role – even more than one at the same time.

The developed classification in Table 4 can be used to react to different requirements for different application cases and to carry out a corresponding functional distribution. Thus, it supports a first high-level recommendation about functional distribution and platform architecture design in the information system engineering, in IT departments and for business executives. The following example illustrates the classification process

Table 4. Classifying functional distribution of IoT platforms

<table>
<tr><th rowspan="3"></th><th colspan="5">IoT platform</th></tr>
<tr><th colspan="3">Centralized</th><th colspan="2">Decentralized</th></tr>
<tr><th colspan="2">Traditional</th><th>Serial interface to DLT</th><th colspan="2">DLT-based</th></tr>
<tr><td>Presentation functionalities</td><td colspan="3">platform provider</td><td colspan="2">various service providers</td></tr>
<tr><td>Analytic functionalities</td><td colspan="3">platform provider</td><td colspan="2">various service providers</td></tr>
<tr><td>Marketplace</td><td colspan="3">platform provider</td><td colspan="2">distributed into P2P-network</td></tr>
<tr><td>Data storage location</td><td>possessed</td><td>platform provider</td><td colspan="3">distributed into P2P-network</td></tr>
<tr><td>Device access</td><td colspan="4">possessed</td><td>various third parties</td></tr>
<tr><td>Basic platform services</td><td colspan="3">platform provider</td><td colspan="2">distributed into P2P-network</td></tr>
</table>

for a cross-domain data scenario using a decentralized IoT marketplace. A farmer owns and operates sensors to measure the soil moisture of his fields (*device access: possessed*). He captures the data in the platform and enriches it with weather data purchased at the IoT marketplace (*device access: various third parties*). In the next step, he uses services from various providers for analysis and visualization purposes, obtained from the marketplace (*analytic and presentation functionalities: various service providers*). At the same time, he stores his own gathered sensor data locally and offers it at the marketplace for sale, e.g., for research institutes (*device access: various third parties and Data storage location: distributed in P2P-network*). Thus, the farmer is at the same time a sensor owner, a data vendor, and a customer purchasing data and services. Besides, he does not have to fear any vendor lock-ins because he is able to change his current vendors and providers platform-internally at any time. By decentralizing and shifting the provision of basic platform services into the P2P-network, the intermediary 'platform provider' becomes obsolete (*basic platform services: distributed into P2P-network*). All participants using the marketplace benefit from this as it prevents the risk of vendor lock-ins, and a reduction in transaction costs may be anticipated [9]. For cross-domain use cases, it can be postulated a DLT-based IoT marketplace is highly recommendable.

6 Conclusion

In order to answer the first research question (RQ1), a systematic literature review was conducted to derive key functionalities of IoT platforms, which served as the basis for the market research to answer RQ2. This market research yields the state-of-the-art regarding currently existing IoT platforms, both traditional and DLT-based. It provides an impression of available solutions and may serve businesses in conducting cross-domain IoT data projects. For answering RQ3, a classification was developed to point out functional distribution within IoT marketplaces. The classification shows that functional distribution from centralized to decentralized is possible across all the elaborated key functionalities of an IoT marketplace. Selective use of DLT may also be reasonably evaluated using the classification developed. The role of DLT may be seen as an enabler of IoT marketplaces for further developments. By supporting micropayments, smart contracts, and the establishment of trust across a network of untrusting participants, DLT allows the operation of an entirely autonomously managed electronic marketplace. It thus enables the development of new business models like the sale of data previously disappearing into data silos, as well as the possibilities for third-party service providers of analytics and presentation functionalities to offer their services directly within the platform – the point where the customer's need for such services occurs.

This paper is not without limitations, and there are three to mention. (1) First, DLT and IoT are still growing exploration fields and are still in progress. Consequently, it has to be emphasized that integrating IoT and DLT introduces new complexity, vulnerabilities, and hazards into platform architectures. (2) Some use cases handle private or sensitive data from closed ecosystems (e.g., sensitive production and machine data of factory environments), which are intended for internal use only. If no intention to share data with third-parties exists, a traditional IoT platform is recommendable, while storing data distributed in a P2P-network is not target-oriented here. It may even be legally questionable under certain circumstances because the data owner might demand full control over the data and its processing at any time. (3) The developed classification needs to be proved by qualitative expert interviews in a further research step.

Three main findings of the paper can be summarized. (1) The paper shows that although many of the functionalities of IoT platforms are still centrally designed today, these functionalities may be designed in a decentralized way as well. Depending on the use case, new business models and approaches may emerge through this functional distribution. (2) Thereby DLT is suitable as an infrastructure technology, especially for marketplace functionalities. The examination shows that IoT platforms also use DLT for data storage and immutable data verification. For developers, this is a key aspect to consider when designing IoT platforms. (3) All in all, IoT marketplaces enable new approaches such as cross-domain sensor data scenarios by making available previously imprisoned data. This emerging business model promises to be profitable and offers completely new opportunities for companies and other organizations in IoT.

The contributions, based on these findings, to the scientific community and practitioners, form a triad. It consists of (1) an overview of state-of-the-art traditional and DLT-based IoT platform solutions, (2) key functionalities of IoT platforms, which have been elaborated in the form of a morphological box, and (3) the developed classification for describing functional distribution within IoT marketplaces.

These findings may prove helpful to address the technical obstacles elaborated by expert interviews. For practitioners, IoT marketplaces are presented as a part of the solution, and a classification for rating their functional distribution is provided. For the realization of DLT-based IoT marketplaces for data, analytic and presentation functionalities, few research and findings exist so far. Thus, it will be a required field of research and practical application in the years to come. For the scientific community, this paper forms a starting point for further research directions.

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