Towards an Understanding of iIoT Ecosystem Evolution - MindSphere Case Study

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Abstract. Currently emerging Industrial Internet of Things (iIoT) platforms form open and flexible networks with the aim of facilitating the integration of various stakeholders in the generation of platform-based added value. The ecosystem emergence process is still underresearched and remains a challenge for the platform providers. In this short paper, we analyze the ecosystem development by Siemens for the platform MindSphere to understand its evolution, based on the sequence of entered partnerships, and their interplay with the established platform boundary resources (BR). Based on this case study, our research identifies insights about how Siemens developed its ecosystem during three distinctive phases. Our analysis demonstrates a roadmap, helping to understand how Siemens managed to integrate distinctive company types as partners in the MindSphere ecosystem. The findings add to the theory on platform emergence by embedding it into a complex Business-to-Business (B2B) context of iIoT.

Keywords: Boundary resources · iIoT ecosystem · Ecosystem emergence

1 Introduction

Digital platforms in iIoT are recognized to enable customized value adding services, integrating external resources from complementing third-party companies through open and flexible interfaces [1, 2]. Even large platform-providing companies such as PTC, Siemens or GE do not have sufficient expertise in each of the industrial processes to cope with the functional heterogeneity in iIoT, so they design open interfaces to integrate third-parties with appropriate external expertise. Therefore, platform-enabled services are usually not created by an isolated company, but consist of hardware and software contributions from external partners, and the integration of the customer, resulting in complex end-to-end (E2E) solutions developed by multiple stakeholders [3–5]. BR build a suitable concept to explain governance actions of platform providers to integrate external resources in ecosystems, and develop new insights on platform emergence [6]. Moreover, the platform-providing keystone is in the position to design and control the determinants, influencing the organization logics, which are required to attract external partners, who are not hierarchically controlled by the platform provider [7]. BR offer technological and social mechanisms to build the required organizational

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logic, and control the knowledge flows to attract the complementors to create value adding platform-based E2E solutions [4, 5, 7–9]. Despite the popularity of the platform topic in the IS [7], the ecosystem development in the B2B domain of iIoT remains an underresearched topic. Only few studies explored emergence phenomena and partner coping strategies for enterprise software platforms [3, 10]. Although BR are considered as a suitable concept to research theory on digital platforms [7], prior research did not use this concept in context of iIoT ecosystems. Bridging the BR perspective with the development of iIoT ecosystems, the research goal is *to understand how are iIoT ecosystems established in the beginning and evolve over time based on business relationships between the iIoT platform provider and its partners*. To achieve this goal, we conduct an explorative and inductive case study analysis of the MindSphere ecosystem, established by Siemens. We identify patterns how Siemens proceeded to develop its ecosystem, and which partnerships in which order it fostered based on the variety of attracted company types, and their connection with established BR.

This paper is a continuation of another research and relies on its results and the same dataset, used to identify 14 distinctive types of BR used in iIoT ecosystems, provided and evolved by Siemens [5]. Previously identified BR (see Table 2) are used to track BR-related actions of Siemens, and to investigate connections between the provision of BR and establishment of partnerships. Our study extends the previously used dataset [5] by additional data sources, additionally considering the information about business relations (with complements and end customers) in the MindSphere ecosystem.

2 Methodology

We have chosen MindSphere for three reasons. Siemens supports the provision of BR, openly communicating the integration of third-parties and strives for a high degree of technological integration at the connected device level. Being developed since November 2015, MindSphere has reached a certain mature status and offers a sufficient information base for researchers [5, 11].

The methodology of the ecosystem study is based upon the longitudinal case study, conducted by Skog et al. [12]. The ecosystem evolution is studied as a process based on tracking of event streams related to BR (dates of initial provision and following changes or evolving actions) and business relationships (date of partnership establishment). In order to track the BR-related actions, we used the previously identified 14 BR [5] used by Siemens, which helps to understand whether the described action is BR-related or not. The analysis of the business relationships included identification of the company type, the partnership type, the purpose of the partnership and the possible connection to a certain BR. These additional characteristics of the two streams allowed us to discover certain patterns how Siemens proceeded to develop its ecosystem and which partnerships in which order it fostered to conduct analytical generalizations about the development of iIoT ecosystems. Our approach corresponds with the qualitative method of document analysis, developed by Bowen. Study of electronic documents allows the extraction of context-based data regarding the BR-related actions and establishment of partnerships. Furthermore, the documents are suitable to track

changes based on their timestamps, thus enabling the researcher to get qualitative knowledge on the ecosystem development based on the available materials in the specific context of iIoT [13, 14]. We relied on the publicly available external articles to verify and enrich the findings [14] from the official press releases. The covered time interval is between early 2016 (public release of MindSphere), and the current time (the 15.08.2019). The developer portal was studied for change logs on relevant BR (such as APIs, SDKs etc.). This approach was effective to track the BR-related actions, but it did not contain a sufficient number of established business relationships between Siemens, and its partners. Therefore, we initiated a follow-up data collection on google.com to track additional partnerships on the websites of the partners. The data analysis included the chronological sorting of the sighted documents as a timeline of events with the help of Aeon Timeline software. Furthermore, we labeled the partner companies according their company type based on the contribution to the iIoT ecosystem and the date of the partnership (either actual date or, if not mentioned in the article, the timestamp of the press release). If an article described something special about a certain partnership (e.g. addition to the platform core technology), then it was labeled as strategic. The list of screened data sources and the number of analyzed articles per data source are depicted in Fig. 1:

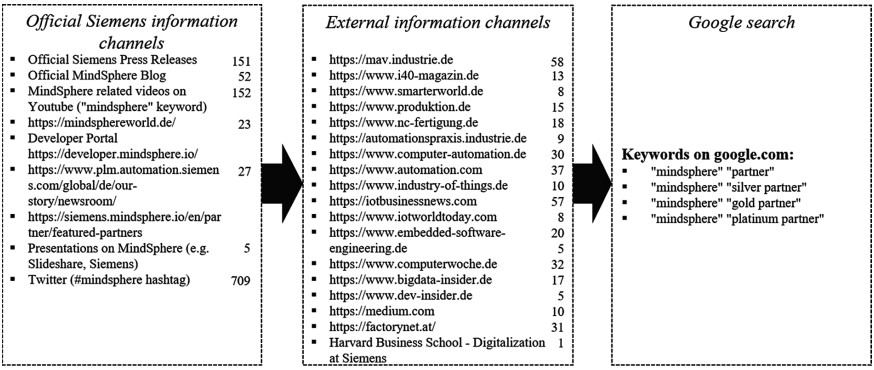

Fig. 1. Data collection overview for boundary resources and ecosystem joins.

3 Results

To observe the development of BR in the MindSphere ecosystem we have divided the timeline between the public release of MindSphere and the 15.08.2019 into three phases, each one is bound to a major release version of the platform. The first phase lasted between the public release of MindSphere and the release of MindSphere 2.0 on the 07.08.2017. The second phase lasted until the release of MindSphere 3.0 on the 01.01.2018. That is when the third phase started and it is currently going on, thus including current Q3 2019. We summarized any new introduction (e.g. support of new cloud infrastructure, or organization of a new type of event), or update (e.g. API patch or documentation update) for each of the 14 previously identified resources [5] in the

following matrix of BR-related actions (Table 1). According to the matrix, there were only few BR-related actions (9 in the first and 10 in the second phase of MindSphere), while during the third phase, the ecosystem development process gained momentum, as indicated by the following 155 partner-engaging actions, related to BR.

Table 1. Tracking of events related with installation or maintenance of BR.

Phases		*1.*						*2.*		*3.*						
Timeline		*Q1 2016*	*Q2 2016*	*Q3 2016*	*Q4 2016*	*Q1 2017*	*Q2 2017*	*Q3 2017*	*Q4 2017*	*Q1 2018*	*Q2 2018*	*Q3 2018*	*Q4 2018*	*Q1 2019*	*Q2 2019*	*Q3 2019*
Technical BR	APIs	0	0	0	0	0	0	0	0	0	6	9	7	13	12	3
	Connectivity Libraries	0	0	0	0	0	0	0	0	0	2	1	2	3	0	2
	Support of Open Protocols	0	0	0	0	0	0	0	0	1	0	0	1	1	0	0
	Infrastructure Support	0	0	0	0	0	0	0	0	1	2	1	0	0	0	1
	DevOps Metrics	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
	SDK	0	0	0	0	0	0	0	0	0	1	0	3	1	4	1
	Cloud Foundry	0	0	0	0	0	1	0	0	1	1	0	0	1	0	0
	App Store	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
	Model-Driven Development	0	0	0	0	0	0	0	0	0	0	1	0	1	2	2
Social BR	Documentation	0	0	0	0	0	2	2	0	0	3	13	4	9	5	5
	Partner Programs	0	0	0	0	0	0	0	1	1	1	1	1	3	1	3
	Onsite Demonstrators	0	0	0	0	0	2	1	1	0	2	0	0	0	1	0
	Events	0	0	0	0	1	1	1	1	0	1	3	2	3	3	2
	Workshops	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
	Start-Up Support	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Sum		**0**	**0**	**0**	**0**	**2**	**7**	**6**	**4**	**4**	**19**	**30**	**20**	**35**	**28**	**19**

The next step required to build a time series of conducted partnerships between third-parties and MindSphere. During the data collection process, we identified 236 business partnerships around MindSphere, and clustered them based on the company type (full list available online at: https://bit.ly/2k9KJAO). The company types combined with the date of partnership helped to recognize which different company types were systematically attracted by Siemens to collaborate during the three phases of development, and if the partnerships were supported by a provision of certain BR (if mentioned).

Shortly after the launch (during the **first phase**), large consulting companies with development capabilities were attracted to promote MindSphere. At the same time Siemens implemented its first industrial IoT-Gateways, which were based upon the hardware boards provided by Intel to provide easy connectivity with MindSphere, and extend the list of own natively compatible hardware products. In order to promote these gateways, and the iIoT platform, Siemens also fostered partnerships with resellers. Nevertheless, at that time there were only few partnerships with software and machine tool companies. However, some BR-related milestones were set during the first phase,

such as the integration of Cloud Foundry as a useful technical BR for the deployment simplification, or the beginning of the opening of digitalization hubs as a social BR.

Table 2. Number of partnerships in the different development phases.

Partners by type	*1. Phase*	*2. Phase*	*3. Phase*
Consulting	5	1	11
Software Technology	2	1	2
Infrastructure	2	1	2
Software as a Service	2	2	44
Reseller	2	0	0
Hardware	1	0	0
Machine Tools	1	2	39
Consumption Goods	1	1	0
Components	1	1	15
Driverless Transport Systems	0	1	0
System Integrator	1	0	7
Data Analysis	1	1	13
Automation	0	0	23
Control Cabinets	0	0	3
Wholesale	0	0	3
Tools	0	0	1
Technology Corporations	0	0	6
Telecommunication	0	1	4
Medical Equipment	0	0	1
Design	0	0	1
Bank	0	0	1
Insurance	0	0	1
Academics	0	0	15
End customer	1	2	10
Sum	**20**	**14**	**202**

During the **second phase,** Siemens initiated various social BR, while the numbers of new partnerships remained low. At that time, the developer portal, first MindSphere application centers, and the first hackathon around MindSphere, were started. Moreover, Siemens started to provide trainings, and finally initiated the startup support initiative to promote them and provide the iIoT platform if needed. Lastly, the official partner program, aiming to facilitate partnerships with software developing companies was launched. Partnerships with consulting companies continued and the startup initiative introduced two new partnerships. Regarding the technology of the platform core, an important strategic partnership was initiated with Software AG to include a device management module in MindSphere. Siemens also started a strategic partnership with Amazon to make MindSphere available on the AWS infrastructure.

In the **third phase**, both the number of new partnerships, and the rates of change for various BR have risen significantly. Shortly after the release of MindSphere 3.0, Siemens started the worldwide user organization "MindSphere World" in six countries in a row, starting with Germany. In the beginning, the user organization primarily included machine tool companies and automation providers. By November of 2018, the organization has received new members with different specializations such as software developing companies, system integrators, banks, industrial wholesalers, and universities. At the same time, the user organization also expanded in Italy, Belgium, Korea, Taiwan, and Japan. Meanwhile, various software developing, and data analysis companies joined the partner program. It is worth mentioning, that some software companies maintain a double membership in the user organization and the partner program. Besides that, three new strategic partnerships were conducted. Hewlett-Packard as a partner enabled platform-based monitoring of additive manufacturing systems. Atos and Rittal were given new strategic roles to foster the development of edge data centres (complementary to the current cloud-based platform). A strategic partnership with the car manufacturer Volkswagen was announced. In total, comparison of BR-related activities and the partner numbers shows similar progressions (see Fig. 2).

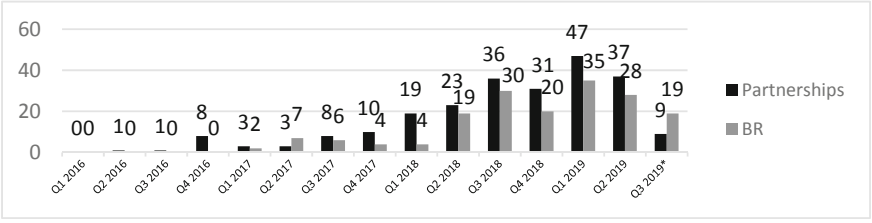

Fig. 2. Values for BR activities and closed partnerships.

The calculated bivariate coefficient indicates a strong correlation based on a value of 0,914800483. The aligning p-value is very low and equals 0,000001784 (see also: https://bit.ly/2k9KJAO). However, the correlation coefficient in this isolated view does not claim to demonstrate a causal relationship between the BR and the ecosystem growth. Interference variables and other dependent variables are not taken into account.

4 Discussion of Key Insights, Limitations and Outlook

Unveiling how Siemens proceeded, we identify **the changing nature of partnerships** as the first contribution. During the first phase, Siemens primarily aimed to cope with infrastructure (SAP, Microsoft) and software technology providers to extend the platform core (Cloud Foundry, IBM). These strategic partnerships expand functional variety and allow a simpler integration of the platform. In comparison, strategic partnerships during the third phase increasingly signaled the maturity of the platform. Exemplary partnerships with Hewlett-Packard and Academics (additive manufacturing), Atos and Rittal (Edge) or Volkswagen (end customer as a global machine

operator), demonstrate the platform is mature enough to conquer new industries, and offer new value creation possibilities for partner. The focus of other partnerships changed as well. While the first phase primarily involved consulting companies to support the fist movers in different industries to integrate MindSphere, the focus shifted during the third phase to either complementary hardware (a total of 77 companies providing machines or components), or software and data analytics companies (a total of 57 companies), as these partner types design the value adding E2E solutions. It is also interesting to note the increasing importance of cyber security (partnerships with McAfee and Kaspersky among the 57 software companies) and academic partnerships. These observations provide an inductive blueprint of a roadmap and may help researchers and decision makers to understand how to overcome the chicken-egg-problem (if neither side will find the platform attractive enough to adopt it, without the presence of the other side) in iIoT ecosystems [15]. The heterogeneity of potential industries to enter, and the variety of potential partner types generate this problem for platform providers in iIoT ecosystems.

The next contribution explores **how a platform provider can address specific company types with BR and combine BR to foster the iIoT ecosystem.** The comparison of BR-related actions and partnerships shows a strong correlation between the amount of implemented and updated BR, and the established partnerships with Siemens. Without the consideration of further interfering factors, the data indicates connection between the BR-related activities of the platform provider and the ecosystem growth, supporting propositions, that ecosystem design is a controllable evolutionary process [7] and BR (as interfaces) must be designed for the third-parties [8]. Specific **BR initiatives may be used to aim specific complementor types** in first place. The partner program for instance was initiated to cope primarily with software developers. The user organization included only industrial companies in the beginning, and software developing companies started to join it later. Some partnerships demonstrate **how BR can be combined**. Some of the software companies had a double membership in the partner program and the user organization, and some partners received a membership in the user organization as a reward after their participation in a hackathon. Thus, the general understanding includes possible combinations of BR by the platform provider to promote certain partners, or to bridge the distance between specific partner types. These insights support the theory proposed by Jacobides et al., as the ecosystem emergence requires different types of relationships (i.e. unique and generic), varying in their standardization degree [7]. The growing importance of social BR during the third phase also supports Gawer's idea of unstable and changing platform interfaces during the time [2]. The standardization degree of the initiated partnerships itself seems to increase over time. The quantitative increase of installed or updated BR in 2019 indicates that Siemens increased the standardization rate of its internal processes to release BR updates at a higher rate. The increased frequency reflects positive effects of standardization on coordination costs of the ecosystem [15], and indicates its evolution mechanism [16]. This observation is supported by the parallel increase of partnerships.

Limitations: The investigation was based upon a single case study and the identified mechanisms and business relationships lack the validating consideration of competing iIoT ecosystems. Therefore, there is no comparison of the BR installed by competitors

and how their ecosystems have grown as a result of similar measures, thus making the generalization of the results challenging. The second limitation is caused by the interpretative approach, which was used to identify the roadmap patterns conducted by Siemens from publicly available documents. This limitation was partly addressed by mixing the official press releases with external sources. However, future interviews with key informants from Siemens could increase the validity of the interpreted data. Furthermore, the information in the examined domain is relatively confidential. According to the tweet of MindSphere CTO [17] we have identified 78% (236/300) of the existing partnerships at best. Certain partnerships are not advertised publicly, and some companies could deliberately disguise the partnership with Siemens to appear more independent. Thus, future interviews could provide a more complete picture of the ecosystem.

Future work: Further analysis of comparable iIoT ecosystems could help to extend the understanding of domain specific factors on the theory of ecosystem development, and identify real "platform leaders" based on the ecosystem size. The results could be used for a future social network analysis of the MindSphere ecosystem and its visualization, replicating the used research method to study other competing iIoT platforms. This could shed light on the simultaneous relationships of complementors (developer multi homing) in the emerging iIoT ecosystems [16]. The identified BR effects and their changing update frequency may be used to explore the changing developer satisfaction with provided BR [8], during the usage of platform technologies.

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