Internet of Things Interoperability Within Communication Scope – Literature Review

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Abstract. *Nowadays, Internet of Things (IoT) trend is emerging and overflowing the reality. The issues regarding the interoperability arisen together with the IoT trend. In this article, we will summarize one of aspects of IoT interoperability to offer the overview of the existing approaches and possibly to identify new opportunities for future researches. The research is conducted by querying relevant databases, analysing relevant articles and summarizing relevant information for better overview. A focus is on communication interoperability. The interoperability is a key feature and the article shows which technologies are the most used in mentioned scope.*

Keywords. Internet of Things, Interoperability, Device Communication

1 Introduction

Industry revolution called Industry 4.0 is currently defining present reality. Internet of thing (IoT) is present quite some time and nowadays it just took off. Everybody is considering it because of digital transformation and Industry 4.0. Internet of things existed for more than 20 years and its popularity arisen just now. It has various forms and there are various vendors having their own ways of producing IoT modules. Which leads towards its heterogeneity and interoperability issues which are tackled in this article. This article is summarizing technologies which are mainly present in architectural and technological aspects of the IoT interoperability.

This article is structured in following way. The section "Research method" focuses on how the research is conducted. The next section "Overview of included papers" brings up the analysis of selected papers. "Results and discussion" contains research findings and discussion about them. The last section "Conclusions" concludes the article.

2 Research Method

The focus of the article is to summarize technologies and concepts that enables the interoperability within the defined scope. The search will be conducted on following databases: IEEE Xplore, Scopus and Web of Science.

2.1 Defined Research Question

The heterogeneity is the issue which will be tackled in this article. The research question is "*Which technologies and concepts enable the interoperability between Internet of Things and systems?*" The question is scoped according to the title after all articles were selected and now it is "*Which communication technologies enable the communication interoperability between Internet of Thing and systems?*"

2.2 Search Strategy

Main keywords are: Internet of Things, interoperability and enterprise. Simple query which would be enough is: "internet of things" AND interoperability AND enterprise. There were multiple search queries for each database according to their search engine shown below.

IEEE Xplore database was searched by conducting a query: `(("Full Text & Metadata":"internet of things" NEAR/5 "interoperab*") AND "Full Text & Metadata":"enterprise" AND NOT "testing")`. Scopus was searched by using following query: `ALL ("internet of things" AND "interoperability" AND "enterprise" AND NOT "testing") AND PUBYEAR > 2014 AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (SUBJAREA , "COMP")) AND (EXCLUDE (DOCTYPE , "re") OR EXCLUDE (DOCTYPE , "cr") OR EXCLUDE (DOCTYPE , "sh")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (ACCESSTYPE(OA)))`. The Web of Science database is searched using this query: `TOPIC: ("internet` `of things" AND "interoperability" AND "enterprise") NOT TOPIC: ("testing").` All queries aim at the same goal: to extract relevant articles about IoT (enterprise) interoperability.

2.3 Selection Criteria

Selection criteria is presented in the Table 1. These criteria are used to determine which paper is relevant and which is not. The table shows all criteria summarized and not in iterations.

Table 1. Inclusion and exclusion criteria

Inclusion Criteria	Exclusion Criteria
Papers written in English	Non-English papers
Papers published between 2015 and 2019 year.	Duplicated papers
Publications in scientific conferences or scientific journals	Out of scope papers.
Papers on IoT interoperability	Papers published before year 2015
Papers which proposed new architectures or approaches	Papers who do not mention communication technologies

3 Overview of the Included Papers

Applying the queries leads to filtering all papers considering the constraints. The section will show the numbers of articles per database, per years and per paper type. Afterwards, the analysis is presented.

3.1 Included Papers

Following section will show numbers of papers selected in each iteration. There are four iterations and its structures are shown in Figure 1. The first iteration is executing the queries to get relevant articles.

The second iteration is a result of reading titles and abstracts. Next iteration is created after reading all articles which would be in scope and which are not. The last iteration is based on shrinking the scope and focusing on one segment of IoT interoperability. 42 papers are analysed and considered.

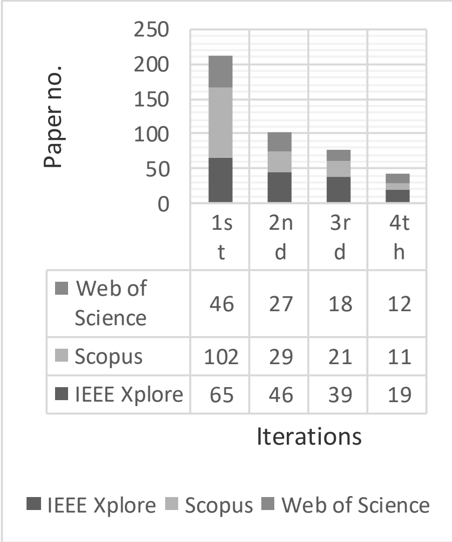

Figure 1. Number papers per database

3.2 Publications Per Years

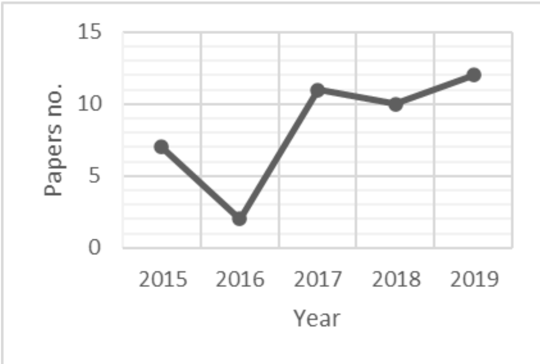

Figure 2. Number of relevant papers per year of publication

The numbers are known, now it will be shown how many papers are published per years as presented in the diagram in Figure 2. The diagram shows how published papers took off until year 2019. It can be concluded that IoT is still being researched which is not strange considering the era of Industry 4.0 and the IoT as one of its enablers.

3.3 Types of Publications

The paper classification based on its type is shown in the Figure 3. The classification is grouped by the database where the papers are found.

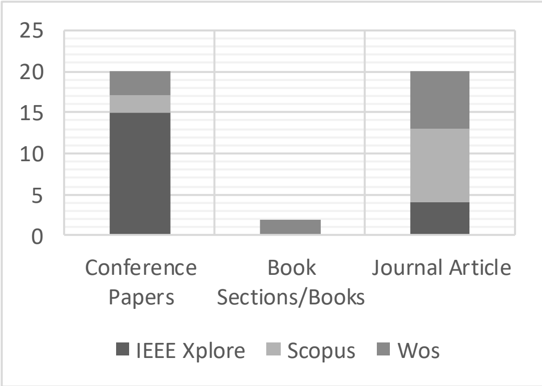

Figure 3. Numbers of relevant papers per type

The diagram shows that relevant papers selected for this article are mainly conference papers and journal articles. The most of conference papers are found in IEEE Xplore because of its search engine which gives the most relevant articles. The Scopus database gave mostly journal articles.

3.4 Citation Analysis

Citation reports are presented in this section. Google Scholar was used to create following tables. Table 2 shows that most of the papers in the article are low-cited papers. This is because of the constraint to look for papers beginning with year 2015. There is decent number of high-cited papers.

Table 2. No. of papers associated with "cited-by" group

Cited by	0	1 - 9	10 - 19	≥ 20
Papers no.	12	21	4	5

The Table 3 presents top 10 most cited papers. The high-cited papers show importance of research in area of the IoT interoperability.

Table 3. Top 10 most cited papers

Rank	Citations	Paper
1	124	(Bröring et al., 2017)
2	85	(Neisse et al., 2015)
3	48	(Derhamy et al., 2017)
4	26	(D’Elia et al., 2017)
5	26	(B. Negash et al., 2015)
6	18	(Roffia et al., 2018)
7	17	(Ismail & Kastner, 2016)
8	16	(Fremantle et al., 2015)
9	10	(Schachinger et al., 2015)
10	9	(Uviase & Kotonya, 2018)

4 Results and Discussion

Authors (Kalatzis et al., 2019) and (Zeid et al., 2019) identify a couple interoperability aspects. Many authors emphasize interoperability importance. The research brings up interesting findings and authors’ tries to conquer the interoperability issues with new architecture or new concepts.

Majority of authors conducted literature analysis on their topic’s background. One of authors conducted literature review to elaborate on their research area (Rejeb et al., 2019), and the other one explained the process of going towards proposed framework and performed literature analysis (Zdravković et al., 2018). These examples are not the only ones, and all literature reviews are mostly covering broader area. They mention technologies listed later in the article. Such references are not meant to be included in this article. Considering the setup constraint, the article focuses on communication interoperability proposed in new solutions. Therefore, mentioned technologies illustrate authors’ preferences during the chosen time period.

A communication between components is one of important factors in achieving interoperability. There is short-range and long-range communication. The short-range communication technologies are Bluetooth, NFC, etc. The focus of the article is on long-range communication which includes using WiFi or mobile internet as enabler. Sometimes, it requires to support more than one communication protocols to reach reasonable level of flexibility in supporting different systems. A couple communication protocols are identified and presented in Table 4. Protocols displayed in the Table 4 are sorted by number of citations next to their name. The most popular communication protocols are at the top of the table. Top 3 communication protocols are Representational State Transfer (RESTful), Message Queue Telemetry Transport (MQTT) and Constrained Application Protocol (CoAP). Research shows that they are mostly used. Surprisingly, the research shows there are attempts to use Blockchain as the enabler for interoperability.

During the research, many interesting attempts to achieve interoperability in other scopes were encountered. There are attempts to use intelligent agents, blockchain, event bus and broker to achieve an appropriate level of communication interoperability.

The variety of protocols makes interoperability harder to achieve and it is a cause of heterogeneity of communication protocols. The vendors should either support multiple protocols or implement standards which would define recommended communication technologies.

Table 4. Communication protocols identified in relevant papers

Communication (#)	Papers
Representational State Transfer - RESTful (24)	(Ahmed et al., 2019; Alexakos et al., 2018; Androcec & Vrcek, 2016; W. Dai et al., 2019; Datta & Bonnet, 2018; Derhamy et al., 2017; Di Martino et al., 2017; Eruvankai et al., 2017; Fremantle et al., 2015; Jin & Kim, 2017; Kalatzis et al., 2019, 2018; Kim-Hung et al., 2017; Krishnan et al., 2018; Lomotey et al., 2017; Behailu Negash et al., 2019; Neisse et al., 2015; Park et al., 2019; Rafferty et al., 2018; Roffia et al., 2018; Saqlain et al., 2019; Schachinger et al., 2015; Touseau & Le Sommer, 2019; Uviase & Kotonya, 2018; Zdravković et al., 2018)
Message Queue Telemetry Transport - MQTT (17)	(Adesina & Osasona, 2019; Busanelli et al., 2019; W. Dai et al., 2019; Derhamy et al., 2017; Eruvankai et al., 2017; Fremantle et al., 2015; Kim-Hung et al., 2017; Lomotey et al., 2017; Behailu Negash et al., 2019; Neisse et al., 2015; Rafferty et al., 2018; Roffia et al., 2018; Saqlain et al., 2019; Touseau & Le Sommer, 2019; Uviase & Kotonya, 2018; Zanfack et al., 2015; Zdravković et al., 2018)
Constrained Application Protocol - CoAP (13)	(Adesina & Osasona, 2019; Alexakos et al., 2018; D'Elia et al., 2017; Derhamy et al., 2017; Eruvankai et al., 2017; Fremantle et al., 2015; Jin & Kim, 2017; Kim-Hung et al., 2017; Lomotey et al., 2017; Roffia et al., 2018; Saqlain et al., 2019; Touseau & Le Sommer, 2019; Zdravković et al., 2018)
Service-Oriented Application Protocol -SOAP (6)	(Androcec & Vrcek, 2016; W. Dai et al., 2019; B. Negash et al., 2015; Behailu Negash et al., 2019; Park et al., 2019; Pradilla et al., 2015)
The OPC Unified Architecture - OPC UA (6)	(Adesina & Osasona, 2019; Ahmed et al., 2019; W. Dai et al., 2019; Eruvankai et al., 2017; Ismail & Kastner, 2016; Saqlain et al., 2019)
Advanced Message Queueing Protocol - AMQP (4)	(Adesina & Osasona, 2019; W. Dai et al., 2019; Eruvankai et al., 2017; Uviase & Kotonya, 2018)
Web Socket (3)	(W. Dai et al., 2019; Kim-Hung et al., 2017; Rafferty et al., 2018)
Extensible Messaging and Presence Protocol - XMPP (3)	(Derhamy et al., 2017; Eruvankai et al., 2017; Zdravković et al., 2018)
Data Distribution Service - DDS (2)	(Lomotey et al., 2017; Murugesan et al., 2017)
Peer-to-Peer - P2P (2)	(H.-N. Dai et al., 2019; Plociennik et al., 2018)
Open Services Gateway initiative - OSGi (2)	(D'Elia et al., 2017; Htaik et al., 2017)
SPARQL Protocol and RDF Query Language - SPARQL (2)	(D'Elia et al., 2017; Roffia et al., 2018)
Decentralized Messaging Framework (1)	(Chainho et al., 2017)
Protocol on-the-fly -Protofly (1)	(Chainho et al., 2017)
Firebase (1)	(Rafferty et al., 2018)
Java Message Service - JMS (1)	(Eruvankai et al., 2017)
Smart Space Access Protocol - SSAP (1)	(D'Elia et al., 2017)
Complex Event processing – CEP (1)	(Zanfack et al., 2015)
Byzantine Fault-Tolerant (BFT) Protocol (1)	(Nuss et al., 2018)
Big IoT API (1)	(Bröring et al., 2017)
DLT intelligent agents (1)	(Plociennik et al., 2018)
Linked Data Notification - LDN (1)	(Roffia et al., 2018)
Event Bus (1)	(Uviase & Kotonya, 2018)
Broker (1)	(Weipeng Li et al., 2015)

5 Conclusions

The goal of the paper is to synthesize available communication protocols aiming at achieving interoperability to identify preferred protocols for new proposed solutions. According to identified trend while analysing selected papers, IoT is currently popular technology because of the Industry 4.0 era and opportunities it offers.

The results show that most popular technologies are RESTful, MQTT and CoAP. Authors propose new approaches and concepts to solve interoperability issue. Most of the authors use the most popular technologies. Aside from new solutions, the authors identify the importance of interoperability and standardization.

The Internet of Things is widely used technology nowadays and it opens opportunities for implementations. The main issue is the interoperability. The authors noticed that and tried to overcome it by implementing multiple protocol support and standards. The experts emphasize the security as an important issue for the future of the IoT. The users' acceptance is highly dependent on the security of the IoT infrastructure. The blockchain technology steps into a picture which is interesting attempt to integrate it into the IoT. It has a potential to resolve two of the IoT issues - interoperability and security.

Some of possible future works or improvements in this area include:

- Definition of standards of communication technologies for IoT
- Research blockchain's opportunities in IoT context
- Definition of multi-protocol solution which will support the most popular communication protocols.

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