A systematic review of Social Internet of Things: concepts and application areas

Completed Research

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Abstract

Internet of Things (IoT) connects machines, devices, sensors and people. This technology is expected to connect billions of devices in the near future. Traditional methods make it very difficult to integrate and maintain so many devices. However, social networks manage to connect and maintain the communication of billions of people using social relationships. Social IoT (SIoT) is an emerging field that uses social relations to connect and maintain devices in IoT networks. This article presents a systematic literature review of conceptual papers in SIoT, together with application areas. The results show two themes from conceptual papers: Objects part of human social loop and have a role in human social network, and Objects form social network. Furthermore the results indicate that, SIoT is mostly applied in smart home environment. These findings will benefit academics and practitioners to better understand SIoT and its applications areas.

Keywords

Social Internet of Things, Social Web of Things, Internet of Things, Social Network.

Introduction

Kevin Ashton coined the term "Internet of Things" (IoT) in 1999, when he proposed the idea of linking radio frequency identification technology with Internet (Ashton 2009). As a result, there has been a rapid development and integration of wireless, web and sensor technologies, which can give life to physical objects like furniture, doors and walls, and make them "smart things" in the digital world. According to forecasts by Gartner (Gartner 2017) and Cisco systems (Evans 2011), the number of connected devices in 2020 will be 20 and 50 billion respectively, which could increase the complexity of the future IoT networks (Gubbi et al. 2013). However, the current IoT integration methods lack universal design standards, are not cost effective and prevent the realization of IoT's true potential (Goad and Gal 2017). There are similarities between the idea behind IoT and the idea of social networks (SN) (Panda et al. 2017). Thus, research carried out on SN can be used to solve implementation problems in the IoT world (Atzori et al. 2012).

Therefore, Atzori et al. (2011a) proposed Social IoT (SIoT) as a new paradigm based on social relationships among objects in IoT networks. Social relationships like parental (devices with same brand and batch), co-location (devices located in same place), co-work (devices that cooperates), ownership (devices owned by same user), and social object (devices with sporadic connections based on user relation) are used for connecting smart objects. The objective of SIoT is *"to keep separate the two levels of people and things; to allow objects to have their own social networks; to allow humans to impose rules to protect their privacy and only access the result of autonomous inter-object interactions occurring on the objects' social network" (*Tripathy et al. 2016). Furthermore, Atzori et al. (2011a) suggested that, by having a SN for smart objects one can achieve the following operations like network navigability, service discovery, and interoperability in a trustworthy environment. Researchers from Ericsson also proposed using SN for IoT

integration and as an analogy/mental model to explain the complexity in user-thing interactions (i.e., the "Social Web of Things" (SWoT)) (Formo et al. 2011). SIoT and SWoT started around 2011, and are being used interchangeably (Ortiz et al. 2014). This paper contributes to both SIoT and SWoT, however the term SIoT is used for both areas. Even though SIoT is still in its infancy stage, considerable research has been done in terms of proposing ideas for integration to actual applications (Gulati and Kaur 2019). This is indicated in the recent special issues in IEEE Internet of Things and Future Generations Computer Systems journals (Fortino et al. 2018; Imran et al. 2019; Rho and Chen 2018). Even though social relationships among objects were introduced as SIoT, the notion of SN is used differently in different studies (Atzori et al. 2014). Despite the increasing popularity of SIoT as an interesting research topic, there are very few studies that have reviewed different notions of SN in SIoT (e.g., Atzori et al. 2014; Chung et al. 2013; Mashal et al. 2015; Ortiz et al. 2014). Also, after 2015, to the best of our knowledge, there is no systematic review which has explored SN concepts in SIoT and their main application areas. Our study is intended to fill this gap by answering the following research questions (RQ): 1. How is the notion of SN used in SIoT? and 2. In which application areas/domains has SIoT been applied?

Related Literature reviews

Previous studies have reviewed the convergence in the early stages of SIoT and SWoT. For instance, Chung et al (2013), investigated the emerging concept of SWoT by reviewing the platform and architecture of various SWoT papers and provided an overview of different ways of using existing SN sites (e.g. Facebook, Twitter) with smart objects. They concluded that SN sites are used as an "authentication server", "monitoring tool", and "interface to share data from smart objects". Mashal et al. (2015) reviewed the fields of IoT, Web of Things (WoT) and SWoT and presented various integration approaches along with design principles and characteristics. Compared to previous studies, they found out that SN sites are being used "as a sensor", "as an actuator", "for importing profile", "for linking smart object profile with user", and "as a communication medium between objects". Ortiz et al. (2014) divided the social roles of SN in relation to SWoT and SIoT in four categories: "SN for objects", "use of online SN and their APIs to maintain structure and relationship with smart objects", "user SN account that helps in service operation", and "SN as an interface to control smart objects". Four different domains of SIoT were also identified like gastronomy, smart cities, smart home and smart shopping. However, they have classified other studies that do not originally fall under the SIoT umbrella. Atzori et al. (2014) reviewed the integration of IoT with SN and presented two main approaches. First, objects are part of the human social loop and have a role within the human SN sites. Second, objects have their own SN, which is independent from human SN but controlled by humans. The reviews were carried out before 2015 and since then the number of studies conducted in this field has increased. Therefore, we carry out a systematic review in order to analyze whether the notion of SN in SIoT still falls under previously discussed categories and to find new emergent categories.

Method

Search strategy

The review was performed based on the guidelines of Okoli and Schabram (2010). Since this topic is closely related to technology, we used the database IEEE Xplore and ACM Digital library which are related to computer science research. However, as the topic is of a multi-disciplinary nature, publications from Web of science, Scopus and Science Direct were also included. The search string was constructed with an operation 'OR' in-between the following keywords: 'Social Internet of things', 'Social IoT', 'SIoT', 'S-IoT', 'Social web of things', 'Social WoT', 'S-WoT'. The keyword 'SWOT' was ignored in order to avoid large number of papers (4000 from Scopus alone) related to SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis. Instead a conjunction of both (SWoT AND "Internet of things") was used. The search was limited to 'title, abstract, and keywords', and articles in English only. Since SIoT was initially proposed in 2011, articles published between 2011 and January 2019 were included. Initial search process was carried out by first author. Inclusion/Exclusion criteria along with their descriptions was discussed and finalized by all three authors. Initially five papers were randomly selected, analyzed and categorized individually by the authors, based on the criteria (Table 1). Following that, the individual analyses were discussed until consensus among the authors was reached. Later, the rest of the papers were screened by first author.

Selection of articles

After obtaining the search results (893 articles), duplicate records (472 articles) were removed. The remaining 421 articles were further screened and selected by applying the exclusion/inclusion criteria (Table 1). The selection criteria and their definitions were borrowed from a systematic review done for industry 4.0 (Liao et al. 2017) and modified to fit the study.

Inclusion /Exclusion	Criteria	Criteria Explanation
Exclusion	Search Engine reason	A paper without English full text.
		Searched Keyword is not in title, abstract or keyword.
	Non-Related	Non-research articles (such as magazines, guest editorial letters, forewords, keynotes, book reviews, and workshop invitations)
		The abbreviation of SIOT/SWOT is not related to social IoT or Social WoT. (e.g., Secure IoT, Semantic WoT, Smart IoT, Symmetric Input Output Table etc).
	Partially Related	SIoT/SWoT is only reviewed or surveyed.
Inclusion	Closely Related	Articles proposing conceptual approaches/theoretical solutions as an architecture/ framework for integrating SN and IoT in SIoT/SWoT.
		Articles about partially/fully completed prototype/application using SIoT concept (not Simulations).

Table 1: Inclusion and Exclusion Criteria (adapted from Liao et al. 2017)

Based on the above exclusion criteria, 181 articles were removed. Then, the full text of 240 articles were assessed for further eligibility. From that, 169 articles that did not meet the inclusion criteria were excluded. If an author published multiple work with the same content, only the main article was selected (e.g., Atzori et al. 2011a; Atzori et al. 2011b; Atzori et al. 2012). In this way, 12 articles were further excluded. Articles reporting both conceptual approaches and a prototype/application were used for both research questions (e.g., Turcu and Turcu 2012; Zhang et al. 2012). In this study, the remaining 59 articles were used in subsequent analysis. Forty-eight were relevant to RQ1 and 28 to RQ2.

Analysis of selected articles

For the RQ1, the articles were categorized into two themes in line with Atzori et al. (2014): 1) Objects part of human social loop and have a role in human SN, and 2) Objects have their own SN independent from human SN. The first theme was further analyzed based on human SN functions found in previous reviews (Chung et al. 2013; Mashal et al. 2015; Ortiz et al. 2014). The second theme was analyzed based on the social relationships that exist between objects (O-O), between objects and humans (O-H), and between objects and also with humans (O-O, O-H). For the RQ2 the selected articles were categorized according to the application areas/domain where SIoT prototypes/applications were implemented.

Results

Convergence of SN and IoT into SIoT

Out of 48 papers, 11 of them were related to the theme that use human SN in their architecture or framework, classified as "Objects part of human social loop and have a role in human SN" (Table 2). Thirty-four papers used the notion of social relationship with objects to form SN and were classified as the theme "Objects form SN" (see Table 3). Nevertheless, 3 papers were classified under both themes (see Table 2 and 3) since they used both human SN and also created social relationships.

Object part of human social network

The results show that there are numerous methods and reasons to integrate existing human SN with IoT. This indicates that human SN played an important role in order to connect humans and their objects. Specific examples are discussed as follows. Two studies used human SN user profiles for authentication to share things (e.g., Chung et al. 2014; Pintus et al. 2011) where a user can log into an IoT platform using the existing SN profile (e.g., Facebook/Twitter). The user can easily import their own profile as well as their friends' contacts who used same IoT platform in order to share smart things with friends (Chung et al. 2014; Pintus et al. 2011). Another reason to import the user profiles and their friendship details was to provide personalized services based on user preferences (Ali et al. 2018). SN was used as a sensor for smart things to retrieve data like user preferences or location for service operations (Pintus et al. 2011). At the same time, SN was used as an actuator for posting the object's status, e.g. on a Facebook wall (Chung et al. 2014) or Twitter (Pintus et al. 2011). SN was also used as an interface for controlling smart objects' environments enabling two-way communication between smart objects and users (Jadhav and Patil 2016; Zhang et al. 2012). Other studies used SN to manage the relationships between objects and also with user (e.g., Byun et al. 2014; Turcu and Turcu 2012). More specifically, Turcu and Turcu (2012) added a robot as a Twitter user to form a relationship with user and other robots, supporting within-robot and robot-human interaction. Finally, SN was also used as a platform for visualizing the smart objects data (Blackstock et al. 2011).

Theme	**SN Functions**	**References**
Objects part of human social loop and have a role in human SN	Authentication	(Chung et al. 2014; Pintus et al. 2011)
	Importing user profile and relationship with their friends	(Ali et al. 2018; Chung et al. 2014; Pintus et al. 2011)
	As a sensor	(Pintus et al. 2011)
	As an actuator/post messages	(Chen et al. 2017; Chung et al. 2014; Nocera and Parchitelli 2018; Pintus et al. 2011; Zhang et al. 2014)
	As an interface to control smart environment	(Jadhav and Patil 2016; Mardini et al. 2017; Zhang et al. 2012)
	Managing relationships with objects	(Byun et al. 2014; Mathew et al. 2016; Shamszaman and Ali 2017; Turcu and Turcu 2012)
	Visualization	(Blackstock et al. 2011)

Table 2: Categorization of the literatures with respect to SN function.

Object form social network

As we mentioned earlier, here the studies used the notion of social relationship and form SN (See Table 3). In this study, we find three different categories of relationships: O-O, O-H, and, O-O and O-H.

Instead of using existing SN as in theme 1, a new platform was created based on human SN model in order to establish a social relationship among objects. In this way, every object can look for the desired service/information using the relationship (friendship) with other objects in order to achieve a common goal (Atzori et al. 2012; Zhang and Shen 2014). Users can add their profiles and impose rules to control the object's behavior. Alan Fiske's "Relational model" (Fiske 1992) was used to derive the relationship among objects (e.g., Atzori et al. 2012; Zhang and Shen 2014). Ruta et al. (2018), proposed an "object's wall" for communication between objects, where objects can post information, like and comment. Some studies made the establishment of object relationship manually by user and some automatically either by pre-defined rules or by recognition/discovery algorithm (e.g., Ali et al. 2018; Atzori et al. 2012). Based on user's relationship with other users, their devices can form social relationship and groups (Huang et al. 2017). Some studies applied the SIoT concept for vehicles to form a vehicular SN where individual vehicles were considered as objects and formed a network (Alam et al. 2014; Shin and Byun 2016). In addition to social relationship among objects, Saleem et al. (2018) added social relationship to applications and formed Social-Cross domain IOT. Whereas Kim and Lee (2015) added relationship of networks, location, and services provided by each device to form a network to identify and locate faults in smart home environment.

To manage smart things, a social model was created between user and things where a user can discover their things and its services (Zhang et al. 2014). Other researchers created a platform or an application for human-object interaction, which mimics human SN (e.g., Cabral et al. 2014; Hussein et al. 2015). In this, things have profiles and interactive/social relationship (friendship) with owners, i.e., an owner can send requests to their things and receive responses from them. As it becomes possible for smart things to have a relationship with owners and integrate with users in a SN environment, Beltran et al. (2014) refer to these smart thing as social things. Rules were set to automatically control smart things and get its status (Nocera and Parchitelli 2018). Hoon-Ki et al. (2014) made it possible to share control function of things with other users (i.e. user sociality). Other authors proposed an intelligent system with a mechanism combining both subjective (user preference, goals, mood), and objective aspects (location, profile) of user, recommending tasks or services to user according to the situation (e.g., Davoudpour et al. 2015; Hussein et al. 2015).

Instead of one-to-one relationship between user and objects, or relationships only among objects, some studies suggested to combine them and create an ecosystem where humans and objects interact within a social framework (e.g., Ciortea et al. 2013; Console et al. 2013). In that framework, both human and objects actively engage with an ability to exchange their knowledge and information with others (things/human) based on the policies set by the user. Relationship between users and things were automatically established based on rules, context or goals (Ciortea et al. 2013; Kim et al. 2015; Ortiz et al. 2014). However, in the study by Console et al. (2013), relationships or links between users-things are not completely automatic. Guo et al. (2012) proposed a human-centric approach to create bi-directional relationship between IoT devices and the user. In that case, objects monitored for opportunity based on users' behaviors to provide awareness to the IoT network, which simultaneously enhanced the social relationship among users. In few studies (e.g., Butt et al. 2018; Raza et al. 2018), authors considered SIoT in the domain of vehicles to limit traffic congestion, and they included network and available infrastructure (road side units), users (passengers, drivers) and vehicles in the SN loop.

Furthermore, three studies combined both approaches, i.e. created a new platform to establish relationships and employed human SN to retrieve user profiles or to post statuses (e.g., Ali et al. 2018; Nocera and Parchitelli 2018; Zhang et al. 2014). For example, Ali et al. (2018), instead of creating new user profiles and their preferences, imported user profiles from SN into the new platform, which enabled things to understand user preferences and suggest services accordingly.

Theme	Social relationship	References
Object form SN	Between objects (O-O)	(Alam et al. 2014; Ali et al. 2018; Atzori et al. 2012; Eddy and Oussama 2018; Gadallah et al. 2017; Gulati and Kaur 2019; Huang et al. 2017; Kim and Lee 2015; Miori and Russo 2017; Nitti et al. 2014; Ruggeri and Briante 2017; Ruta et al. 2018; Saleem et al. 2016; Shin and Byun 2016; Voutyras et al. 2015; Wei et al. 2018; Zhang and Shen 2014)
	Between object and Human (O-H)	(Beltran et al. 2014; Cabral et al. 2014; Davoudpour et al. 2015; Hoon-Ki et al. 2014; Hussein et al. 2015; Hussein et al. 2017; Nocera and Parchitelli 2018; Zhang et al. 2014)
	Between objects (O-O) and also with Human (O-H)	(Butt et al. 2018; Ciortea et al. 2013; Console et al. 2013; Guo et al. 2012; Kim et al. 2015; Leng et al. 2018; Mathew et al. 2013; Ortiz et al. 2014; Raza et al. 2018; Romero et al. 2017; Saleem et al. 2016; Sinha and Kumar 2016)

Table 3: Categorization of the literatures with respect to Social Relationship

Existing SIoT Application Areas/Domain

From the analysis of 28 articles relevant to RQ2 we found that SIoT was applied and tested mainly in smart home environments (see Table 4). Examples were for controlling and interacting with smart things (e.g., Cabral et al. 2014; Hussein et al. 2015), for home safety (Chung et al. 2014), or energy efficiency (Marche et al. 2017). Some studies applied SIoT concepts in smart office environments (e.g., Davoudpour et al. 2015; Zhang et al. 2014), or industry (Leng et al. 2018). Apart from specific application areas, some developed a

general platform based on SIoT which can be later used to develop any application scenario (e.g., Girau et al. 2017; Pintus et al. 2012).

Application Areas/Domain	**References**	**Studies (N)**
Smart Home	(Cabral et al. 2014; Chung et al. 2014; Cicirelli et al. 2016; Hussein et al. 2015; Jadhav and Patil 2016; Kang et al. 2016; Kim et al. 2015; Marche et al. 2017; Mardini et al. 2017; Rau et al. 2015; Ruta et al. 2018; Zhang et al. 2012)	12
Smart Office	(Davoudpour et al. 2015; Zhang et al. 2014)	2
Transportation	(Carpanen et al. 2016; Shin and Byun 2016)	2
Industry	(Leng et al. 2018)	1
Gastronomy	(Console et al. 2013)	1
Water quality monitoring	(Peres et al. 2013)	1
Robot	(Turcu and Turcu 2012)	1
Museum	(Ali et al. 2018)	1
Elderly monitoring service	(Miori and Russo 2017)	1
Airport	(Hussein et al. 2017)	1
General Platform	(Byun et al. 2014; Girau et al. 2017; Girau et al. 2013; Hoon-Ki et al. 2014; Pintus et al. 2012)	5

Table 4: Existing SIoT Application areas /Domain

Discussion

The main aim of this paper was to explore the notion of SN used in SIoT, and also give an overview of existing application areas in the context of SIoT. The results from our review indicate that included studies followed different approaches for integrating IoT with SN. A small number of studies used existing human SNs to enable smart objects to be part of user social circles. However, the majority of the reviewed studies created a new platform in order to have a social relationship among objects and also with users. Also, this study identifies two new categories under objects form SN theme. First, including social relationships "Between Object and Human (O-H)" where platforms which mimic human SN to support interaction of user and smart things and to share smart things with others. Second, social relationships "Between Objects and also with Human (O-O, O-H)", where both user and smart things form an ecosystem in order to be actively engaged for knowledge and information exchange with others to achieve a common goal. From the findings, the studies mainly created social relationships among objects to make objects socialize on their own, which is in line with the original objective of SIoT (Atzori et al. 2011a). It is also evident from Table 3 that many studies proposed humans to be included in the objects social loop and actively be engaged and become prosumers (producer and consumer). Pintus et al. (2015) refer to this as the new era of Internet, i.e., the Humanized Internet of things (H-IoT). By analyzing the existing application areas in SIoT, it was shown that the majority of the prototypes were implemented in smart homes and not so much in other areas. Although many studies discussed the idea of SIoT for transportation in the name of Social Internet of Vehicle, they did only simulations to evaluate their concepts (e.g., Alam et al. 2014; Nitti et al. 2014). Going further, there is a tendency that other domains for possible SIoT application could be healthcare and smart cities (Maglaras et al. 2016; Turcu and Turcu 2018). Additionally, very few studies are currently done in areas such as elderly monitoring service, industries, and environmental monitoring. Also, many other application areas such as agriculture, retail chains, smart grid needs to be explored.

The study is associated with the following limitations. First, only papers under SIoT and SWoT were considered. It has to be acknowledged that there are other technologies for integrating social aspects and IoT such as Cyber Physical Social System, Socialized Devices, Device Social Network, etc. that were not

included. Second, forward and backward searches were not done since we judged that out choice of databases covered a sufficient wide range of articles. Third, articles which applied the SIoT concepts by simulations are not considered for application areas. In future work, comparison between the other technologies and SIoT could give more insight about the evolution of Social IoT.

Conclusion

In this paper, we provided an overview of the literatures proposing to integrate SN and IoT, together with existing application areas in the context of SIoT. To achieve this, we conducted a systematic literature review and classified the papers into two main themes: objects part of human social loop and have a role in human SN, and objects that form a SN. Additionally, an overview of existing application areas in SIoT was presented. This study may help researchers aiming to understand the convergence of SN and IoT and existing research areas in SIoT. This study also provides valuable insights for practitioners in different domains who are interested in adopting SIoT. Despite having various ways for IoT integration based on the notion of SN, successful adaptation of this paradigm can change how we engage with technology in the future.

Acknowledgement

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement number 754285.

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