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Liu, Fei; Tan, Chee-Wee; Lim, Eric T. K.; Choi, Ben

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Fei Liu

Department of Computer Science, Hong Kong Baptist University, Hong Kong, China

Phone: +852 6732-4969

Email: fliu09@comp.hkbu.edu.hk

Chee-Wee Tan

Department of IT Management, Copenhagen Business School, Copenhagen, Denmark

Phone: +45 3815-4468

Email: cta.itm@cbs.dk

Eric T.K. Lim

The School of Information Systems, Technology & Management, UNSW, Sydney, Australia

Phone: +61 (2) 9385-4688

Email: e.t.lim@unsw.edu.au

Ben Choi

The School of Information Systems, Technology & Management, UNSW, Sydney, Australia

Phone: +61 (2) 9385-9843

Email: chun.choi@unsw.edu.au

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Research on the Internet of Things (IoT) has been booming for the past 6 years due to technological advances and potential for application. Nonetheless, the rapid growth of IoT articles as well as the heterogeneous nature of IoT pose challenges to conducting systematic review of IoT literature. This study seeks to address the abovementioned challenges by reviewing 1,065 IoT articles retrieved from ISI Web of Science via a blend of quantitative citation analysis and qualitative content analysis. For the former, we generated a historiography of IoT research, a citation network, in which we tried to identify main paths of codification and diffusion, as well as path-dependent transitions. For the latter, we explicated the progression of knowledge through 30 central IoT articles in a chronological order regarding infrastructures, enabling technologies, potential technologies, and research challenges. Findings from this study contribute to both IoT research and management.

Keywords: Internet of Things; algorithmic historiography; citation network; codification; diffusion.

Introduction

The Internet of Things (IoT) is an emerging paradigm that aims to unify physical objects via the deployment of various network architectures, including ad-hoc networks and the Internet. The IoT industry has thrived for the past few years, and this growth does not show signs of abating any time soon. According to Business Insider (BI) Intelligence Estimates, 25 billion IoT devices will be installed by 2020 across enterprises, homes and public infrastructures (Moon, 2016). For this reason, IDC anticipates that the size of the global IoT industry is likely to hit USD $7 trillion dollars (Moon, 2016) with the bulk of the growth being concentrated in four key markets. First, the connected-home market will grow from USD $61 billion dollars in 2016 to nearly USD $490 billion dollars in 2019 (Danova, 2014). Second, the IoT-related healthcare market is estimated to grow from USD $22.47 billion dollars in 2015 to USD $117 billion dollars in 2020 (Moon, 2016). Third, the cloud-enabled robotics market has started to gain momentum from 2010 onwards and is expected to attract USD $40 billion dollars in investment by 2020 (Moon, 2016). Lastly, the global aerial drone market is predicted to increase from USD $6 billion dollars in 2013 to approximately USD $16 billion dollars in 2024 (Ballve, 2014). The rapidly expanding market for the IoT industry has also captured investors' attention. Specifically, the amount of investment commitments to the IoT industry have tripled while the number of deals doubled in 2015 (i.e., 1,045 million US Dollars in 94 deals) as compared to that in 2013 (i.e., 381 million US Dollars in 59 deals).

By and large, the boom of the industry can be attributed to the growing scholarly and practitioner interest in IoT ever since Schoenberger (2002) published his seminal article in Forbes about radio-frequency identification (RFID). Specifically, he envisioned a future in which things would be connected through the newly invented RFID chips, which in turn facilitates the identification and surveillance of a physical object via a unique electronic product code (Schoenberger, 2002). The concept of IoT is defined as "a world-wide network of interconnected objects uniquely addressable, based on standard communication protocols" (Atzori, Iera, & Morabito, 2010, p. 2788). Many researchers, on the other hand, subscribed to a more precise definition for IoT:

> A dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual 'Things' have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network (Xu, He, & Li, 2014, p. 2233)

From above, it is clear that the definition of IoT captures the complexity and heterogeneity of this multi-disciplinary phenomenon. Essentially, the IoT paradigm comprises three interconnected visions, namely thing-, Internet- and semantic-oriented visions. The thing-oriented vision accentuates the technologies that grant a physical object visibility, traceability, and computational capability (Atzori et al., 2010). The Internet-oriented vision emphasizes the technologies and protocols that enable ad-hoc network of physical objects as well as addressability and reachability of the physical objects in Internet (Atzori et al., 2010). The third vision, semantic-oriented vision, is concerned with the means to represent, store, integrate, search, organize, and ultimately derive meaning from IoT-generated information (Atzori et al., 2010). Furthermore, the architecture that enables IoT (i.e., SOA-based architecture) is also multi-layered. In general, the IoT architecture comprises three incremental layers. The object layer represents the network of physical objects, including sensors and actuators, that identifies the objects in, collects information from, and shapes the real world (Atzori et al., 2010; Domingo, 2012; Gubbi, Buyya, Marusic, & Palaniswami, 2013; He, Yan, & Xu, 2014; Xu et al., 2014). The middleware and network layer creates virtual representation of the physical objects, handles transfer of data and control command, as well as composes and manages services (Atzori et al., 2010; Domingo, 2012; Gubbi et al., 2013; He et al., 2014; Xu et al., 2014). Lastly, the application layer utilizes the functionalities of the middleware and acts as an interface between the available services and end users (Atzori et al., 2010; Domingo, 2012; Gubbi et al., 2013; He et al., 2014; Xu et al., 2014). In an ecosystem where anything communicates, anything identifies, and anything interacts (Miorandi, Sicari, De Pellegrini, & Chlamtac, 2012), IoT should be recognized as an imbrication between technology development (c.f., He et al., 2014) and managerial implication (c.f., Xu et al., 2014).

The growing popularity and heterogeneous nature of IoT pose challenges to a proper synthesis of previous IoT literature. In particular, IoT studies often come with divergent focuses, which hinders knowledge assimilation and accumulation within extant literature. Furthermore, the explosive growth of IoT research due to its popularity exacerbates the problem of heterogeneity, leading to an insurmountable barrier in conducting a systematic literature review on the phenomenon. In this study, we aim to address the aforementioned issues by performing a systematic literature review on prior IoT research through a blend of both quantitative and qualitative approaches.

Specifically, we turn to citation analysis, which is founded on the basis of algorithmic historiography, as our quantitative approach to literature review (Lucio-Arias & Leydesdorff, 2008; Porch, Timbrell, & Rosemann, 2015). Citations represent the historical dependency of scientific developments and acts as a means of unveiling two types of relationships: *codification* and *diffusion* (Lucio-Arias & Leydesdorff, 2008). *Codification* is observed when a 'citing' article draws inspiration from a body of knowledge, which is codified in the form of reference, representing a retrospective perspective of the citation history (Leydesdorff & Wouters, 1999). In contrast, *diffusion* refers to a dissemination of knowledge from the original article, which 'is cited by' a more recent article. This more recent article thus resembles a prospective view of the citation history (Lucio-Arias & Leydesdorff, 2008). By employing HistCite to generate a historiography, which refers to a network of citations, of the 30 most essential IoT articles from a list of 1,060 IoT articles retrieved from ISI Web of Science, we seek to identify both *codification* and *diffusion* via *main-path analysis* (Lucio-Arias & Leydesdorff, 2008). In addition, we also explore possible *path-dependent transitions*, which represent critical transitional articles that exist outside the main paths of *codification* and *diffusion* (Lucio-Arias & Leydesdorff, 2008). Our quantitative approach provides us with the platform to qualify the progression of knowledge in the most essential IoT articles and to derive insights in cutting-edge IoT research thereafter via *qualitative content analysis* (Porch et al., 2015).

We expect to answer the following three research questions through our dual-approach literature review for IoT research:

- What are the core research articles in the field of IoT?
- What is the main path of progression for the core research articles in the field of IoT?
- How does knowledge progress in the field of IoT?

By answering the above three research questions, this study can contribute to future IoT research and development by summarizing the enabling technology and architecture for IoT, the challenges to the development of IoT, as well as the prospects of IoT application. This study can also serve as a guide to how systematic literature review can be accomplished via a combination of quantitative and qualitative approaches.

The paper is structured as follows: Following this introduction, we will supply details on our research methodology for deriving a historiography of citations, for conducting *main-path analysis*, and for exploring *path-dependent transitions*. Findings of our quantitative analysis will then be explicated to include both paths of *codification* and *diffusion*, as well as the identification of *path-dependent transitions*. Subsequently, we will elaborate on the knowledge progression in IoT research via qualitative content analysis. We will then conclude with a discussion of the implications and limitations of this study.

Research Methodology

To attain rigor in our review of extant literature, we adhered to the four-stage process for systematic literature review, namely planning, selection, extraction, and execution (Okoli & Schabram, 2010). In the remainder of this section, we outline our research approach under the guidance of this four-stage process.

Planning

The planning stage is concerned with the clarification of the purpose of the literature review, the protocol to be enacted and the training required for this endeavor (Okoli & Schabram, 2010). Because the purpose of this literature review is to illuminate the citation structure and knowledge progression in previous IoT literature, we analyzed the citation history of past studies via a combination of *HistCite*, a software package for bibliometric analysis and visualization, and *Pajek*, a toolkit for network analysis and visualization. Established protocol for deploying HistCite and Pajek was adapted from prior research to ensure quality in the analysis of previous literature (Lucio-Arias & Leydesdorff, 2008; Porch et al., 2015).

Selection

In line with Okoli and Schabram's (2010) recommendations, our selection stage embodies both literature search and article screening. To be assured of the comprehensiveness of our coverage of IoT articles, we searched the ISI Web of Science database for all articles pertaining to the topic of 'internet of things' or 'IoT' by applying the advanced search query: "TS=(internet of things OR IoT)". This search query retrieved a relatively large dataset of 2,685 IoT articles. Because of our decision to concentrate on the technological and managerial aspects of IoT, we fitered out articles in the research domain of *arts and humanities*, culminating in 2,635 remaining articles. We further eliminated articles that are not written in English, resulting in a preliminary collection of 2,571 IoT articles.

Extraction

In the extraction stage, we appraised the quality of retrieved articles and extracted relevant information (Okoli & Schabram, 2010). In order to ascertain that every article in our preliminary collection is centered on IoT rather than containing a tangential reference to the term, we downloaded and read the abstracts of the 2,571 articles in the collection. As a consequence, we excluded 1,506 articles that are not directly related to the subject of IoT, yielding a final dataset of 1,065 articles for analysis. Figure 1 summarizes the annual publication counts as well as the cumulative global citation scores from 1993 to 2016. As Figure 1 depicts, IoT is a young research field that only started to attract scholarly attention in 2009 and the number of publications has skyrocketed ever since. In 2015 alone, 434 IoT articles were published, a number that is astronomical compared to a mere 7 publications on the topic in 2009. This trend of publication is a testimony to the growing popularity of IoT within the academia.

- Insert Figure 1 about Here -

To extract the citation structure among the 1,065 IoT articles, we imported their citation file into HistCite. HistCite identified the 30 most influential articles among all imported articles in accordance with the Local Citation Score (LCS), which refers to the number of times an article is cited by others in the local collection (Garfield, 2004). By limiting our citation analysis to the 30 most influential articles, we were able to: (1) elucidate the most highly cited articles that contribute significantly to the development of the research domain (Griffith, Small, Stonehill, & Dey, 1974), and; (2) yield a legible visualization of the citation structure without the risk of overcrowding (Lucio-Arias & Leydesdorff, 2008). Table 1 demonstrates the 30 most influential articles elicited by HistCite. This set of articles was employed for further data extractions, which include the generation of *algorithmic historiography*, the computation of *main-path analysis*, the exploration of *path-dependent transitions*, and the conduct of *content analysis*.

- Insert Table 1 about Here -

Algorithmic Historiography

HistCite utilizes the reference lists of the aforementioned 30 articles to reconstruct a chronological network of citations. Since citations can reflect the propagation of information through a collection of articles (Garfield, 1979; Ramos-Rodríguez & Ruíz-Navarro, 2004), the algorithmic historiography generated by HistCite serves as an instrument for us to identify patterns and temporal trends in previous IoT literature via quantitative and qualitative analyses. Figure 2 illustrates the algorithmic historiography for these 30 articles. The algorithmic historiography is essentially a chronological network of citations in which each vertex represents an article and each edge indicates the directional relationship of citation (i.e., the *priori* article at the head of the arrow is cited by the *posteriori* article at the tail of the arrow). The number inside the vertex correlates to the label number in Table 1 whereas the size of the vertex reflects the local citation score of an article, meaning the number of times an article is cited by others in a local collection (i.e., collection of 1,065 IoT articles).

- Insert Figure 2 about Here -

Main-Path Analysis

Main-path analysis was employed to examine the dominant path in an acyclic network that is time dependent by identifying the most representative vertices at distinct moments of time (Lucio-Arias & Leydesdorff, 2008). The representativeness of a vertex is reflected by its degree of centrality, which refers to the number of vertices that are connected to this particular vertex. In a citation network, the degree of centrality comprises both the number of citations received by an article (i.e., *indegree*) and the number of cited references in the article (i.e., *outdegree*). (Lucio-Arias & Leydesdorff, 2008). A main path is reconstructed though those articles with high degree centrality until the path reaches an article that is no longer cited or one that contains no more references within the local collection (Batagelj, 2003).

Both paths of *codification* and *diffusion* can be identified via *main-path analysis*. The default citation network generated by HistCite can be employed to identify the codification process because it showcases the 'citing' relationship between articles, meaning that the direction of each edge goes from a more recent article to one of the earlier article it cites in time (Lucio-Arias & Leydesdorff, 2008). By transposing the matrix that denotes the citation network, we can uncover the 'cited by' relationship between articles and in turn, identify the diffusion process (Lucio-Arias & Leydesdorff, 2008). We essentially reverse the direction of each edge to go from an earlier article to a more recent one that cites it.

To conduct the *main-path analysis*, we import both the 'citing' network and the 'be cited by' network into Rajek. We then apply the main-path algorithm to leverage on each article's relative position in terms of 'citing' and 'be cited by' in order to unveil the underlying structural backbone of the collection of articles. According to guidelines advocated in prior research, we chose the search path link count algorithm (Lucio-Arias & Leydesdorff, 2008), which takes into account all possible search paths through the network when estimating the main path (Hummon & Dereian, 1989).

Path-Dependent Transitions

Path-dependent transitions refers to critical articles that forges path dependencies or obligatory passing points (Callon, 1984). Specifically, a *path-dependent transition* can be construed as an intermediate article between two directly connected articles (i.e., a *priori* article and a *posteriori* article that cites the priori one) such that the bridged path can better explain the transition between a priori article and a posteriori article, leading to shortened information distance (Lucio-Arias & Leydesdorff, 2008). In this sense, exploring *path-dependent transitions* can help us to identify critical intermediate articles that are hidden on the periphery of main paths through a citation network.

To capture the information distance between two articles in terms of their bibliographies, we calculate the information value I (Kullback & Leibler, 1951) that a posteriori article contribute to the priori article via the formula below:

$$I(q:p) = \sum_{i=1}^{n} q_i \log_2 \left(\frac{q_i}{p_i}\right) \quad (1)$$

In this formula, p_i refers to the occurrence of the ith reference in a priori article whereas q_i represents the occurrence of the ith reference in a posteriori article. The occurrence of a reference f_i is derived in accordance with the number of appearance of this reference among the 30 most influential articles and is normalized at the level of the local collection f_i/N (Lucio-Arias & Leydesdorff, 2008). To avoid encountering a zero denominator, all occurrences are increased by unity so that a zero occurrence becomes $1/N$ and so forth (de Solla Price, 1981; Elliott, 1971). I reflects the informational contribution in terms of bibliography made by a posteriori article to a priori article cited by the former (Lucio-Arias & Leydesdorff, 2008).

In order to compare the two paths with respect to their information distances, we calculate the difference in two information value *I*s via the formula below:

$$I(q:p) - I\left(q:p'\right) = \sum_i q_i \log_2 \left(\frac{q_i}{p_i}\right) - \sum_i q_i \log_2 \left(\frac{q_i}{p'_i}\right) = \sum_i q_i \log_2 \left(\frac{p'_i}{p_i}\right) \quad (2)$$

Formula (2) contains a new notation p'_i, which represents the occurrence of the ith reference in an intermediate article. Formula (2) allows us to validate the existence of *path-dependent transition* p' if $I(q:p) - I(q:p') > I(p':p)$ (Lucio-Arias & Leydesdorff, 2008). A conformation of the above inequality equation bears different implication for *codification* and *diffusion*. For *codification*, a *path-dependent transition* resembles a chronologically closer approximation to a cited priori article (Lucio-Arias & Leydesdorff, 2008). On the other hand, a *path-dependent transition* acts as an auxiliary transmitter that enhances the information dissemination from a priori article to a posteriori one in the case of *diffusion* (Lucio-Arias & Leydesdorff, 2008). The analysis for *path-dependent transitions*, which identifies transformative articles that disrupt the continuation of priori articles' influence on the following posteriori articles, is complementary to the *main-path analysis* by uncovering the continuous flow in a body of literature (Lucio-Arias & Leydesdorff, 2008).

Execution

According to Okoli and Schabram (2010), the execution stage comprises an in-depth scrutiny of findings from prior research in order to consolidate past studies and present a coherent picture of extant literature. Consistent with the procedures described in the preceding sections, we performed: (1) *main-path analysis*, and; (2) analysis of *path-dependent transitions* for both codification and diffusion conditions. Additionally, we conducted content analysis to synthesize findings in previous IoT literature. Results of our analysis will be presented in the following sections.

Results of Quantitative Analysis

Main-Path Analysis

Figure 3 illustrates the main paths for both *codification* and *diffusion* through the citation network of the 30 most influential IoT articles (i.e., most highly cited articles in the IoT community) that is generated by applying the search path link count algorithm in Rajek. To better position the two main paths into the citation network, we superimposed the results of *main-path analysis* onto the algorithmic historiography generated by HistCite (see Figure 4).

- Insert Figure 3 about Here -

- Insert Figure 4 about Here -

The main path for codification identifies central articles and demonstrates how an earlier central article was codified by a later one (Lucio-Arias & Leydesdorff, 2008). According to our analytical results, Welbourne et al.'s (2009) work on RFID technology as well as Broll et al.'s (2009) work on Near Field Communication (NFC) and Physical Mobile Interaction (PMI) are the earliest influential IoT articles. Subsequently, there is a sequential codification through Atzori et al.'s (2010) review of IoT, Miorandi et al's (2012) highlights of the vision, applications and research challenges of IoT, as well as Xu et al.'s (2014) review of industrial IoT. Each of these three seminal articles resembles a codification of previous work in IoT field and is thus regarded as being the most influential in the advancement of IoT research.

By transposing the matrix of citation network, the main path for *diffusion* illustrates the dissemination of knowledge through central articles instead (Lucio-Arias & Leydesdorff, 2008). Interestingly, the main path of *diffusion* diverges from that of *codification* after passing through Atzori et al.'s (2010) cardinal work. Results show that Welbourne et al.'s (2009) insights into RFID and Broll et al.'s (2009) innovation of NFC and PMI sparked the initial ideas about IoT, which converge at Atzori et al.'s (2010) review of IoT. Beyond that, Atzori et al.'s (2010) vision and architecture of IoT diffused to both Domingo's (2012) proposed IoT application for people with disabilities and Gubbi et al.'s (2013) incorporation of cloud computing into IoT. This knowledge is further disseminated into three central articles: Bi et al.'s (2014) integration of IoT with Enterprise Systems (ESs) and modern manufacturing, Xu et al.'s (2014) review of industrial IoT, and He et al.'s (2014) vehicular data cloud service for auto-parking in IoT environment.

Path-Dependent Transitions

To explore *path-dependent transitions,* we isolated all intermediate articles as well as the priori and posteriori articles they bridge. Table 2 summarizes our analytical results for *path-dependent transitions*. Results attest to the non-existence of *critical transitions* in the citation network of 30 most influential IoT articles for both *codification* and *diffusion*. Accordingly, for *codification*, there is no alternative article that distracts the main path whereas for *diffusion*, there is no auxiliary transmitter that facilitates the dissemination of ideas. Taken together, our results point to the absence of a disruptive paradigm shift in IoT research at the moment, which is understandable for two reasons. First, the field of IoT is still in an infancy stage of development with limited knowledge accumulation. Moreover, the heterogeneity of IoT has led to a fragmented research landscape so much so that a dominant paradigm has yet to emerge. Nonetheless, since the citation network of IoT research is devoid of *path-dependent transitions*, it lends credibility to the robustness of the main paths of *codification* and *diffusion* as identified in this study.

- Insert Table 2 about Here -

Results of Quantitative Analysis

Chronological Content Analysis on Central Articles

Guided by the algorithmic historiography generated by HistCite (see Figure 1) as well as the main paths identified by employing Rajek, we conducted a content analysis on the findings of the 30 most influential IoT articles in a chronological order. Our content analysis focuses on infrastructures/overarching frameworks, enabling technologies, potential applications, and research challenges in the IoT context (see Table 3). In 2009, two key enabling technologies for IoT emerged, marking the origins of IoT research. Notably, RFID (Welbourne et al., 2009) and NFC (Broll et al., 2009) represent the most successful attempt to breach the boundary between physical and virtual worlds, enabling individuals to identify (e.g., search for and track objects) and interact with real world objects (e.g., ticketing and mobile payment) via the Internet infrastructure. Nonetheless, these technological breakthroughs are also accompanied by corresponding challenges for researchers to tackle. These challenges include the derivation of meaning from IoT-generated data, privacy and socio-economic issues as well as the optimal balance between reliability and intuition (Broll et al., 2009; Welbourne et al., 2009).

- Insert Table 3 about Here -

In 2010, the first comprehensive Service Oriented Architecture (SOA) for IoT was proposed in Atzori et al.'s (2010) seminal article by delineating the IoT paradigm into three interconnected visions (i.e., things-orientation, Internet-orientation, and semantic-orientation). Specifically, the SOA encapsulates three layers from top to bottom: applications layer, which offers service to end-users; middleware layer, which connects physical technologies with the application layer via three sub-layers (i.e., service composition, service management, and object abstraction); and objects layer, which represents a network of identifying, sensing, and communicating objects (Atzori et al., 2010). SOA thus lay the groundwork upon which subsequent IoT research flourishes. Around the same time, the smart object (Kortuem, Kawsar, Fitton, & Sundramoorthy, 2010), which exemplifies the duality of physical and digital entities, embedded context-aware interface design (Kranz, Holleis, & Schmidt, 2010). The IoT field also begins to see the emergence of topics such as enterprise information system with physical devices (Guinard, Trifa, Karnouskos, Spiess, & Savio, 2010), Sensor Networks for an All-IP World (SNAIL) (Hong et al., 2010), as well as the establishment of connections among Intranet of Things (Zorzi, Gluhak, Lange, & Bassi, 2010). As a consequence, IoT research went beyond identifying, tracking, and interacting with physical objects to the digitization of physical objects. Fresh opportunities for applying IoT became apparent, such as peer-to-peer reasoning (Kortuem et al., 2010), context-aware kitchen, embedded computing for entertainment and sports (Kranz et al., 2010), dynamic registration of devices (Guinard et al., 2010), assisted living, e-health, enhanced learning, smart industry, intelligent transportation, and smart environment (Atzori et al., 2010). Although a few challenges previously encountered by the IoT community have been solved, like those associated with reliability and usefulness, new challenges surfaced, including the dilemma between embeddedness and interaction (Kranz et al., 2010), issues with energy consumption, standardization, quality of service (QoS) control, object authenticity, data integrity, digital forgetting (Atzori et al., 2010), IPv6 adaptation, security (Hong et al., 2010), and the level of heterogeneity (Zorzi et al., 2010).

In 2011, IoT research started to focus on solving the security issues after the major breakthroughs in 2010 as highlighted above. Roman et al. (2011) discussed the adoption of Transport Layer Security (TLS), Public Key Cryptography (PKC), and Key Management Systems (KMS) to secure the Wireless Sensor Networks (WSN). Zhou and Chao (2011) proposed a Media-Aware Traffic Security Architecture (MTSA) that includes key management, batch rekeying, watermarking, and authentication in order to offer a secure IoT environment while facilitating diverse multimedia services. Last but not least, Roman et al. (2011) presented the Internet Engineering Task Force (IETF) standards (i.e., 6LowPAN, ROLL, CoRE, and CoAP) in an attempt to address plausible threats such as protocol and network security, data privacy, identity management, trust and governance, as well as fault tolerance. Despite the emphasis on security, Jara et al. (2011) continued to expand IoT applications by advancing an architecture for diabetes therapy management in Ambient Assisted Living (AAL) environments on the basis of personal RFID cards.

In 2012, two seminal articles were published. Domingo (2012) subscribed to the IoT architecture that consists of the perception layer, the network layer, and the application layer as well as the networking technologies (e.g., WiMAX, ZigBee, 6LoWPAN, and MANET) to assist people with disabilities across various environments (e.g., smart home and smart school). In his article, Domingo (2012) also raised awareness of the challenges of customizability, self-management, and developing Brain-Computer Interfaces (BCIs). In a way, Domingo’s work (2012) facilitates the diffusion of the impact of IoT. Conversely, Miorandi et al. (2012) synthesized the vision, applications and research challenges pertaining to IoT, which in turn is instrumental to the effort in codifying prior IoT research. Miorandi et al. (2012) summarized system-level IoT features, the progress made in the standardization of IoT protocols (e.g., NFCIP, GMSA, ONS, and M2M), potential applications (e.g., smart home, smart city, health-care, and smart management), as well as research challenges (e.g., distributed system, fragmentation, and interoperability). The remaining influential articles published in this year investigated other aspects of IoT. For instance, Branaghi et al. (2012) proposed the notion of machine-interpretable and self-descriptive data, as well as AI knowledge engineering to utilize big data generated by the IoT. Bormann et al. (2012) contributed to the standardization of data transfer protocol by proposing the

Constrained Application Protocol (CoAP). López et al. (2012) presented an architecture for smart objects that can be deployed to monitor supply chain whereas Atzori et al. (2012) introduced the Social Internet of Things (SIoT) as a novel paradigm for integrating objects into users' social network to facilitate resource discovery and sharing. From above, it is evident that the dominant IoT research tradition at this particular juncture in time was to contribute to the standardization of IoT and explore novel applications within the IoT domain.

In 2013, Gubbi et al. (2013) pushes the diffusion of IoT research by bringing cloud computing (i.e., Aneka cloud platform) into the IoT infrastructure to assume the role of middleware. The ubiquitous connectivity, data analytics, and information representation enabled by cloud computing not only expedite information sharing, but they also enable knowledge generation and autonomous decision making (Gubbi et al., 2013). Gubbi et al. (2013) also pointed out that the IoT has already reached the plateau of productivity in accordance with Gartner' Hype Cycle of Emerging Technologies. Other influential IoT research endeavored to address the emerging issues pertaining to the IoT. Specifically, Palattella et al. (2013) tackled power consumption issues by applying the IoT protocols for low-power communication whereas Li et al. (2013) advanced an IoT architecture with Compressed Sensing (CS) to deal with the ever growing IoT data in order to conserve energy and communication resources. Besides, IoT research continued to discover viable IoT applications, such as anti-counterfeiting via tracing the supply chains (L. Li, 2013).

Three central IoT articles were published in 2014. Bi et al. (2014) introduced the IoT in Enterprise Systems (ESs) for manufacturing to integrate virtual enterprise, enterprise application, as well as machines and devices. Bi et al. (2014) furthered the diffusion of IoT research by pointing to the future direction of realizing automated decision making, agility, adaptability, and reconfigurable capabilities through the incorporation of IoT into manufacturing. Likewise, He et al. (2014) diversified IoT research by adopting Vehicular Ad-Hoc Networks (VANET), cloud computing, and cloud service system for automobiles (DARWIN system) to develop IoT-based vehicular data clouds for services like automatic parking. Xu et al.'s (2014) review for industrial IoT contributed to the codification of prior IoT research by summarizing the technology progress in the IoT field as well as the SOA for IoT while recommending novel IoT applications (e.g., Food Service Centre, mining production, and firefighting) and research trends (e.g., social networking with IoT, green IoT, context-aware IoT, AI in IoT, smart objects, and cloud computing in IoT). Other influential studies around this period of time also contributed to the expansion of IoT research frontiers. Particularly, Perera et al. (2014) explored context-aware life cycle in the IoT context and put forth promising directions for future research such as the understanding of sensor data, context discovery, sensing-as-a-service, and context sharing. He and Xu (2014) proposed the Enterprise Service Bus (ESB) as a backbone for connecting distributed enterprise systems (i.e., logistics, material flow, and supply chain management). Lastly, Fan et al. (2014) explored the topic of the IoT service design by applying automating design methodology framework and ontology-based resource reconfiguration to design a IoT-based clinical rehabilitation system. In hindsight, 2014 denotes the emergence of IoT research in the industrial context, which further testifies to the increasingly pivotal role played by IoT in driving productivity.

Discussion

Theoretical and Managerial Implications

By conducting a methodical review of prior research in the IoT context, we seek to contribute to extant IoT literature in four ways. First, our novel and systematic approach to literature review can serve as a guide for future studies that seek to identify key articles and the main paths of *codification* and *diffusion* in a certain research field. Second, by deriving the citation network as well as identifying the main paths of *codification* and *diffusion* through the network, we are able to visualize how central IoT articles synthesized previous literature as well as how they inspire and aid in the diversification of subsequent research. Third, we followed up on our quantitative analysis with qualitative content analysis to derive knowledge from the progression of the most influential IoT articles. Particularly, we uncovered the progression of IoT research through the bridge between the physical and digital realms, establishing SOA for IoT, the address of security issues, the standardization of protocols, the incorporation of cloud computing, and the eventual adoption of the IoT in industrial context. We further pinpointed infrastructures, enabling technologies, potential applications, and research challenges for IoT at each stage. Finally, this study prescribes strategies for positioning new studies in a body of research. For instance, to stay in the main path of *codification*, authors can choose to publish an article that synthesizes prior research. Conversely, to tread the main path of *diffusion*, authors can strive to integrate novel topic with findings from previous literature. An article can also potentially disrupt the main paths by introducing a transformative paradigm into a body of literature.

Findings generated by our qualitative content analysis also contain managerial guidelines. First, the research trend identified in previous IoT literature can infuse practitioners with the necessary background knowledge to aid them in harnessing the benefits of IoT. Second, we summarized the enabling technologies for IoT, therefore providing practitioners with a comprehensive and exhaustive set of technological profiles to configure IoT infrastructures. Third, this study consolidated a collection of potential applications of IoT, which may inspire practitioners to apply IoT in their own businesses. Lastly, the list of potential issues pertaining to IoT, as uncovered in this study, can compel practitioners to stay vigilant and take precaution against potential risks of employing IoT.

Limitation and Future Research

This study comes with its limitations that can potentially be addressed by future research. First, due to the immaturity of the IoT literature at the moment of review, we were not able to identify any *path-dependent transitions* within our collection of highly influential articles, which in turn limits the exemplary potential of this study. Future studies can replicate our approach when paradigm shifts emerge in IoT literature in order to identify *path-dependent transitions*. Nonetheless, the lack of critical transitions attests to the robustness of the main paths we identified through the citation network. Second, since our literature review evolves around the citation-based historiography generated by HistCite, the most recent IoT articles fall out of the scope of this study due to insufficient cumulative citations for these articles (Lucio-Arias & Leydesdorff, 2008). For this reason, we have deliberately chosen to focus on the most impactful rather than the latest articles in IoT field. Future study may review the most recent IoT articles that relate to the impactful IoT research we identified in this study.

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Table 1. Most Influential IoT Articles			
Label No.	**Authors & Year**	**Journal Title**	**LCS (Local Citation Score)**
35	Atzori et al. (2010)	Computer Networks	232
103	Miorandi et al. (2012)	Ad Hoc Networks	73
226	Gubbi et al. (2013)	Future Generation Computer Systems	66
25	Kortuem et al. (2010)	IEEE Internet Computing	43
31	Guinard et al. (2010)	IEEE Transactions on Services Computing	36
18	Welbourne et al. (2009)	IEEE Internet Computing	35
43	Zorzi et al. (2010)	IEEE Wireless Communications	34
250	Li et al. (2013)	IEEE Transactions on Industrial Informatics	32
61	Roman et al. (2011b)	Computer	25
175	Li (2013)	Business Horizons	23
116	Atzori et al. (2012)	Computer Networks	21
93	Domingo (2012)	Journal of Network and Computer Applications	20
322	He and Xu (2014)	IEEE Transactions on Industrial Informatics	19
470	Xu et al. (2014)	IEEE Transactions on Industrial Informatics	19
49	Roman et al. (2011a)	Computers & Electrical Engineering	16
383	He et al. (2014)	IEEE Transactions on Industrial Informatics	16
44	Shelby (2010)	IEEE Wireless Communications	15
378	Bi et al. (2014)	IEEE Transactions on Industrial Informatics	15
57	Zhou and Chao (2011)	IEEE Network	14
73	Barnaghi et al. (2012)	International Journal on Semantic Web and Information Systems	14
381	Fan et al. (2014)	IEEE Transactions on Industrial Informatics	13
54	Jara et al. (2011)	Personal and Ubiquitous Computing	12
91	Bormann et al. (2012)	IEEE Internet Computing	12
122	Palattella et al. (2013)	IEEE Communications Surveys & Tutorials	12
269	Perera et al. (2014)	IEEE Communications Surveys & Tutorials	12
42	Hong et al. (2010)	IEEE Wireless Communications	11
95	López et al. (2012)	Personal and Ubiquitous Computing	11
20	Broll et al. (2009)	IEEE Internet Computing	10
366	Wang et al. (2014)	IEEE Transactions on Industrial Informatics	10
26	Kranz et al. (2010)	IEEE Internet Computing	9

Table 2. Results of the Analysis for Path-Dependent Transitions											
Codification						**Diffusion**					
p	***p'***	***q***	***I(p':p)***	***I(q:p) - I(q:p')***	**Critical transition**	***p***	***p'***	***q***	***I(p':p)***	***I(q:p) - I(q:p')***	**Critical transition**
18	35	93	0.152	0.070	No	93	35	18	0.095	0.013	No
18	43	93	0.046	0.032	No	93	43	18	-0.025	-0.039	No
18	35	226	0.152	0.075	No	226	35	18	0.085	0.008	No
18	43	226	0.046	0.015	No	226	43	18	-0.014	-0.044	No
18	35	378	0.152	0.070	No	378	35	18	0.046	-0.036	No
18	43	378	0.046	0.018	No	378	43	18	-0.060	-0.089	No
25	119	470	0.086	0.061	No	470	119	25	-0.051	-0.076	No
31	103	220	0.255	0.126	No	220	103	31	0.229	0.101	No
31	220	470	0.032	0.029	No	470	220	31	-0.082	-0.084	No
31	103	470	0.255	0.131	No	470	103	31	0.140	0.016	No
31	322	470	0.196	0.112	No	470	322	31	0.068	-0.016	No
35	226	383	0.098	0.027	No	383	226	35	0.087	0.016	No
35	93	470	0.098	0.027	No	470	93	35	0.042	-0.029	No
35	103	470	0.208	0.091	No	470	103	35	0.140	0.023	No
35	116	470	0.035	0.003	No	470	116	35	-0.026	-0.058	No
35	174	470	-0.024	-0.026	No	470	174	35	-0.087	-0.088	No
35	226	470	0.098	0.036	No	470	226	35	0.042	-0.020	No
35	103	220	0.208	0.086	No	220	103	35	0.229	0.108	No
35	116	220	0.035	0.003	No	220	116	35	0.059	0.027	No

Table 3. Summary of Core Findings from the Most Influential Articles					
No.	**Authors & Year**	**Infrastructure/Overarching Framework**	**Enabling Technology**	**Potential Application**	**Research Challenge**
18	**Welbourne et al. (2009)**	Radio Frequency Identification Device (RFID) Ecosystem	• RFID • Electronic Product Code (EPC) • Controlled access to RFID data • Physical Access Control (PAC) policy	• Search Engine for Things • Social networking application (Rfidder) • Personal trend (Digital Diary) • Event-Based Desktop Search • Personal object and friend tracking	• Deriving meaning from low-level RFID data • Usefulness rather than novelty • Privacy • Economical issue
20	**Broll et al. (2009)**	Pervasive service interaction framework: • Web service • Interaction proxy • Mobile device • Physical object	• RFID • Near Field Communication (NFC) • Physical Mobile Interaction (PMI) • Multi-Tag Interaction (MTI)	• Service discovery and invocation, information retrieval, • Ticketing, • Mobile payment	• Reliability • Ease of use and intuitiveness
25	Kortuem et al. (2010)	Dual paradigm of physical and digital entities	• Flow-based programming • Smart objects (representation, awareness, interactivity	• Peer-to-peer reasoning with smart objects	• Smart objects' interactive capabilities
26	Kranz et al. (2010)	Embedded Human Computer Interaction (HCI) interfaces	• Context-aware Internet of Things (IOT) • Small Embedded Objects	• Context-Aware Kitchen Utilities, • Capacitive Touch Input on Clothes, • Embedded Computing for Entertainment and Sports,	• Embedded vs. interaction devices • Invisibility dilemma • Implicit vs. explicit interaction • Context dependence Interaction and multimodality • Development support
31	Guinard et al. (2010)	Service-Oriented Architecture (SOA)	• Web service standards (DPWS) • Web-oriented patterns (REST)	• Integrating physical devices into enterprise information systems • dynamically register devices and the services • Automatic augmentation of the search queries	N/A
35	**Atzori et al. (2010)**	IoT paradigm • Things-oriented vision • Internet-oriented vision • Semantic-oriented vision Service Oriented Architecture (SOA) • Application, • Service composition, • Service management, • Object Abstraction, • Objects, • Trust, security and privacy throughout	• RFID • Sensing Technologies • EPC • Unique/Universal/Ubiquitous IDentifier (uID) • NFC • Wireless Sensor and Actuator Networks (WSAN) • Spime: smart items • Coordination and Support Action for Global RFID-related Activities and Standardization (CASAGRAS) consortium, • Internet Protocol for Smart Objects (IPSO), • Internet Ø, • Web of things, • wireless personal area networks • (WPAN)	Private User: • Domotics • Assisted living • E-health • Enhanced learning • Enhanced game room • Social networking Business User: • Automation • Industrial manufacturing • logistics • business/process management • Intelligent transportation • Smart environment • Robot taxi	• Reduction in terms of size, weight, energy consumption, and cost • Standardization • Mobility support • Naming • Transport protocol • Traffic characterization and Quality of Service (QoS) support • Authentication • Data integrity • Privacy • Digital forgetting
42	Hong et al. (2010)	Sensor Networks for an All-IP World (SNAIL) • Mobility protocol, • Web enablement protocol,	N/A	• Facilitate suitable wireless sensor network • Adapting Internet Protocol (IP) to the space of things	• Internet Protocol Version 6 (IPV6) Adaptation • Mobility • Web enablement • Time synchronization

		• Time synchronization protocol, • Security protocol			• Security
43	Zorzi et al. (2010)	A new resolution infrastructure for linking physical entities and devices in the IoT: Intranet of Things to Internet of Things	N/A	• Discovery of the relevant entities • Lookup of IoT devices that can provide information allow interactions • Monitoring IoT devices and entities and keeping the dynamic links between them up-to-date	• Heterogeneity • Connectivity • Scale • Naming, addressing and identification • Privacy & security • Self-management capabilities
49	Roman et al. (2011)	N/A	• Secure Socket Layer/Transport Layer Security (TLS/SSL) • Public Key Cryptography (PKC) • Key management systems (KMS)	N/A	• Security of Wireless Sensor Networks (WSN)
54	Jara et al. (2011)	Patient's profile management architecture based on personal RFID cards	• RFID • IPv6 over Low power Wireless Personal Area Networks (6LoWPAN)	• Diabetes therapy management in Ambient Assisted Living (AAL) environments • Personal-care devices	N/A
57	Zhou and Chao (2011)	Media-Aware Traffic Security Architecture • Key management • Batch rekeying • Watermarking • Authentication	N/A	N/A	N/A
61	Roman et al. (2011)	N/A	IETF standards • 6LowPAN • ROLL • Constrained RESTful Environments (CoRE) • Constrained Application Protocol (CoAP)	N/A	• Protocol and network security • Data and privacy • Identity management • Trust and governance • Fault tolerance
73	Barnaghi et al. (2012)	N/A	Semantic technologies in IoT • Information modelling • Ontology design • Processing of semantic data	• Machine-interpretable and self-descriptive data in IoT • Knowledge engineering and AI techniques	• Interoperability • volume, velocity and volatility of the IoT data
91	Bormann et al. (2012)	N/A	• Constrained Application Protocol (CoAP) • Representational State Transfer (REST)	N/A	N/A
93	**Domingo (2012)**	IOT architecture • Perception layer • Network layer • Application layer	• Wireless Local Area Networks (WLANs) • Worldwide Interoperability for Microwave Access (WiMAX) • Bluetooth • Ultra-wideband (UWB) • ZigBee • General Packet Radio Service (GPRS), • Wide band Code Division Multiple Access (WCDMA) • IPv6 over Low-power Wireless Personal Area Networks (6LoWPANs). • Mobile Ad-hoc Network (MANET), • REST based Constrained Application Protocol (CoAP)	• Assisting people who are visually impaired, hearing impaired, and physically impaired via context-awere and implanted chips • Smart shopping (ShopTalk, Grozi, Automatic payment) • Smart school (RFID, Augmented Reality) • Smart home	• Customizability • Self-management (self-configuration, self-healing, self-optimization and self-protection) • Standardization • Depth of connection • Scalability • Security and privacy issues • Brain–computer interfaces (BCIs)

			• RFID		
95	López et al. (2012)	Architecture that uses Smart objects to integrate technologies: • Automatic identification • Sensor systems • Embedded processing • Context-aware • Adhoc networking • Internet-based services	• Smart objects	• Real-time monitoring of goods flowing through a supply chain	• Economic challenges • Security and trust issues • Scalability challenges
103	**Miorandi et al. (2012)**	System-level IOT features • Devices heterogeneity • Scalability • Ubiquitous data exchange through proximity wireless • technologies • Energy-optimized solutions • Localization and tracking capabilities • Self-organization capabilities • Semantic interoperability and data management • Embedded security and privacy-preserving mechanisms Security in IOT • Data confidentiality, • Privacy, • Trust	Standardization • Near Field Communication Interface and Protocol (NFCIP) • Global System for Mobile Communications Association (GMSA), • Electronic Product Code (EPC) • Object Naming Service (ONS) • Institute of Electrical and Electronics Engineers (IEEE) 802.15 Working Group • European Telecommunications Standards Institute (ETSI) technical committee on Machine-to-Machine (M2M) • Semantic Sensor Network by W3C	• Smart Homes/Smart Buildings • Smart Cities • Environmental monitoring • Health-care • Smart business/Inventory and product management • Security and surveillance	• Distributed Intelligence • Distributed Systems • Computing Communication Identification • Security • Fragmentation, • Lack of adequate standards, • Interoperability • Standardization
116	Atzori et al. (2012)	Social Internet of Things (SIoT) paradigm • Sensing of the physical World • Data transport • Service discovery module • Service composition module • Gateway Object Relationship profiles • Parental • Co-location • Co-work • Ownership • Social	N/A	• Service/resource discovery • Information/resource sharing	• Requiring a continuous communication with the servers • Efficiency in resource discovery
122	Palattella et al. (2013)	Protocol stack for IoT • Low Power Communication Stack • Highly Reliable Communication Stack • Internet-Enabled Communication Stack	• Low-power physical layer (IEEE 802.15.4-2006) • Power-saving link layer (IEEE 802.15.4e) • Internet Engineering Task Force (IETF) 6loWPAN • Internet Engineering Task Force (IETF) Routing Over Low power and Lossy (ROLL) networks	N/A	N/A
175	Li (2013)	N/A	• RFID and EPC network	• Tracing and tracking goods in supply chains • Verifying product authenticity	• Privacy
226	Gubbi et al. (2013)	Hype Cycle of Emerging Technologies • Technology trigger,	• Micro-Electro-Mechanical Systems (MEMS)	Personal and Home • Ubiquitous healthcare • Control of home	• Architecture integration • Energy efficient sensing • Secure reprogrammable

		• Peak of inflated expectations, • Trough of disillusionment, • Slope of enlightenment, • Plateau of productivity • IoT Framework with Cloud Computing • Applications • Could computing • Wireless Sensor Networks (WSN) Network of Things	• Wireless communications • Digital electronics • Aneka cloud platform, • Sensor-Actuator-Internet framework • RFID • WSN • Addressing schemes • Data storage and analytics • Visualization	equipment • Social networking Enterprise • Factory maintenance • Smart Environment IoT • Citizens • Transport • Services Utilities • Smart grid and smart metering • Video based IoT • Water network monitoring and quality assurance of drinking water Mobile • Traffic congestion • Supply chain efficiencies • efficient logistics management	networks and privacy • Quality of Service due to heterogeneity • New protocols • Participatory sensing • Data mining: complex sensing data • Geographic Information System (GIS) based visualization • Cloud computing (Scheduling, Multi-objective optimization, Task duplication based fault tolerance, International activities)
250	Li et al. (2013)	IoT Architecture with Compressed Sensing (CS) • Data Acquisition Networks • Internet Network • Data Analysis Networks	• Compressed information sampling • Compressed Distortion-Minimizing Control • Compressed Information Reconstruction • Compressed Distortion-Minimizing Control	N/A	• Saving energy and communication resources
269	Perera et al. (2014)	Context life cycle • Context Acquisition, • Context Modeling, • Context Reasoning, • Context Distribution	• Context acquisition methods (Push vs. Pull, Instant vs. Interval, Direct sensors vs. Middleware vs. Context servers, Physical vs. Virtual vs. Logical) • Semantic web ontology languages [Resource Description Framework (RDF) vs. Web Ontology Language (OWL)] • Context modelling and representation techniques (Key-value, Markup, Graphical, Object, Logic, Ontology) • Context reasoning decision modelling techniques (Supervised learning, Unsupervised learning, Rules, Fuzzy logic, Ontology-based, Probabilistic logic)	N/A	• Understanding sensor data • Automated configuration of sensors, • Context discovery • Selection of sensors in sensing-as-a-service model • Security, privacy, and trust • Context sharing
322	He and Xu (2014)	An SOA-oriented integration environment using Enterprise Service Bus (ESB)	• Distributed Computing Environment (DCE) • Distributed Component Object Model (DCOM) • Common Object Request Broker Architecture (CORBA) • Java Remote Method Invocation (RMI) • Message Oriented Middleware (MOM) • Java 2 Enterprise Edition (J2EE) • Microsoft's .Net Framework • SOA and ESB	• Logistics systems • Material flow systems • Supply chain management systems	• Standardization and quality assurance • Integration of heterogeneous devices and applications • Reusability • Privacy and security • Scalability and customizability of middleware

			• Grid Computing • Cloud Computing		
366	Wang et al. (2014)	N/A	• Enterprise Systems (ESs) • Cloud computing • Matrix M for assembly relations • Extended Matrix for assembly paths	Assembly modelling and planning: • Design, • Manufacturing, • Assembly, • Logistics, • Marketing, • Supplier	N/A
378	**Bi et al. (2014)**	IoT for modern manufacturing • Virtual enterprise and enterprise alley (cloud computing) • Enterprise application (grid computing) • Machines and devices (ubiquitous computing)	• Ubiquitous computing • Wireless Sensor Networks • IPv6 • WiFi and Wimax • Zigbee, bluetooth, and RFID • A mobile platform offers communications for anytime, • anywhere, and anything • Cloud computing	• Assisting peoples with disabilities • Personalized health care systems • Service-oriented middleware • Smart grid • Real-time transportation management and optimization • Decentralized decision-making • Flat and dynamic organization	• Combination of automated decision-making and IoT • Challenges of data management in IoT • Security and privacy • Standardization • Massive data • Heterogeneous environment • Agility and adaptability for real-time changes • Reconfigurable capabilities
381	Fan et al. (2014)	Combining ontology-based resource reconfiguration and intelligent design methodology to produce a subsystem of IoT-based rehabilitation system • Master • Server • Things	• Ontology-based resource reconfiguration • Automating design methodology framework	• Clinical rehabilitation	N/A
383	**He et al. (2014)**	Architecture for IoT-based vehicular data clouds • Cloud computing, • Middleware, • Communication technology, • Web of things (car and street)	• Vehicular ad-hoc networks (VANET), • Cloud computing (PaaS, IaaS, SaaS) • Cloud service system for automobiles (DARWIN system) • Sensors • RFID • GPS • Mobile devices	• IoT-based vehicular data clouds • Intelligent parking cloud service • Mining Vehicular Maintenance Data Service • Vehicular Data Mining Cloud Service	• Scalability and technology integration • Performance, reliability and quality of service • Security and privacy • Lack of global standards for device and service integration, security • Privacy, architecture, and communications
470	Xu et al. (2014)	IOT architecture • Sensing layer • Networking layer • Service layer • Interface layer • Security and privacy throughout	• Identification and tracking technologies • Communication technologies in IoT • Networks involved in IoT • Service management in IoT	• Healthcare service industry • IoT Food Service Centre (FSC) • Safer mining production • Transportation and logistics • Firefighting	• Performance and cost of SOA of IOT • Heterogeneity of the network • The lack of common language • Interference of objects in the network • Standardization (lower the entry barrier, consistency) • Definition of security and privacy • Trust and reputation mechanism, • Communication security • Privacy of communication and user data • Security on services and applications • Integrating Social Networking With IoT Solutions, • Green IoT • Context-aware IoT middleware solutions,

					• Employing AI Techniques to Create Intelligent Things or Smart Objects • Combining IoT and Cloud Computing

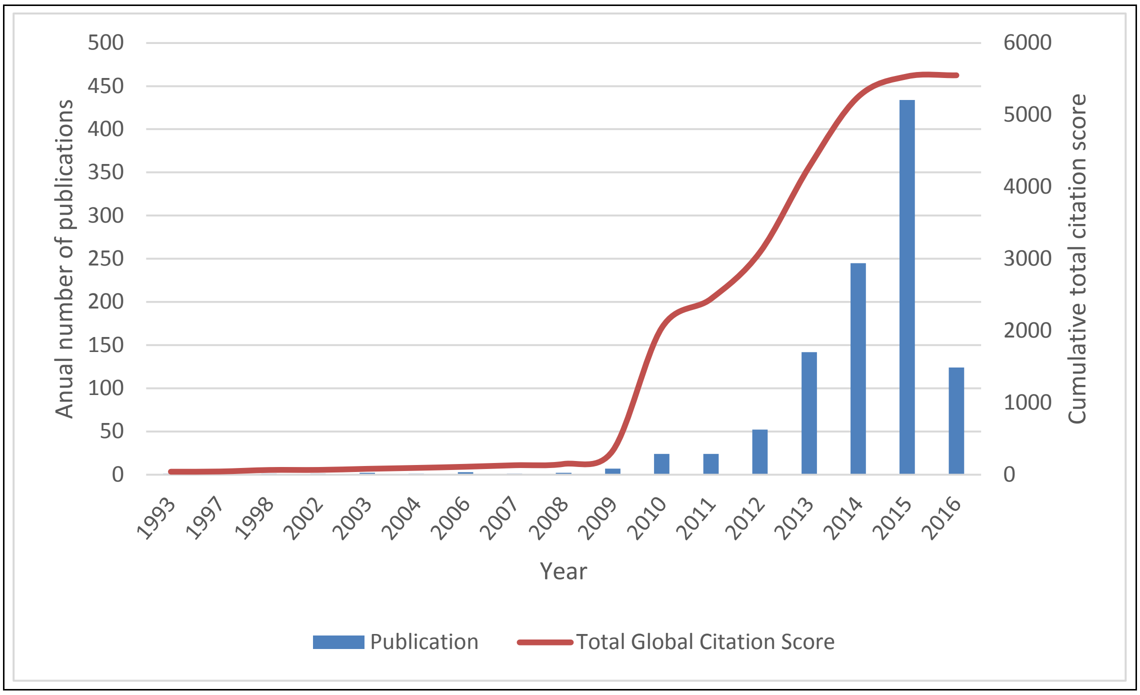
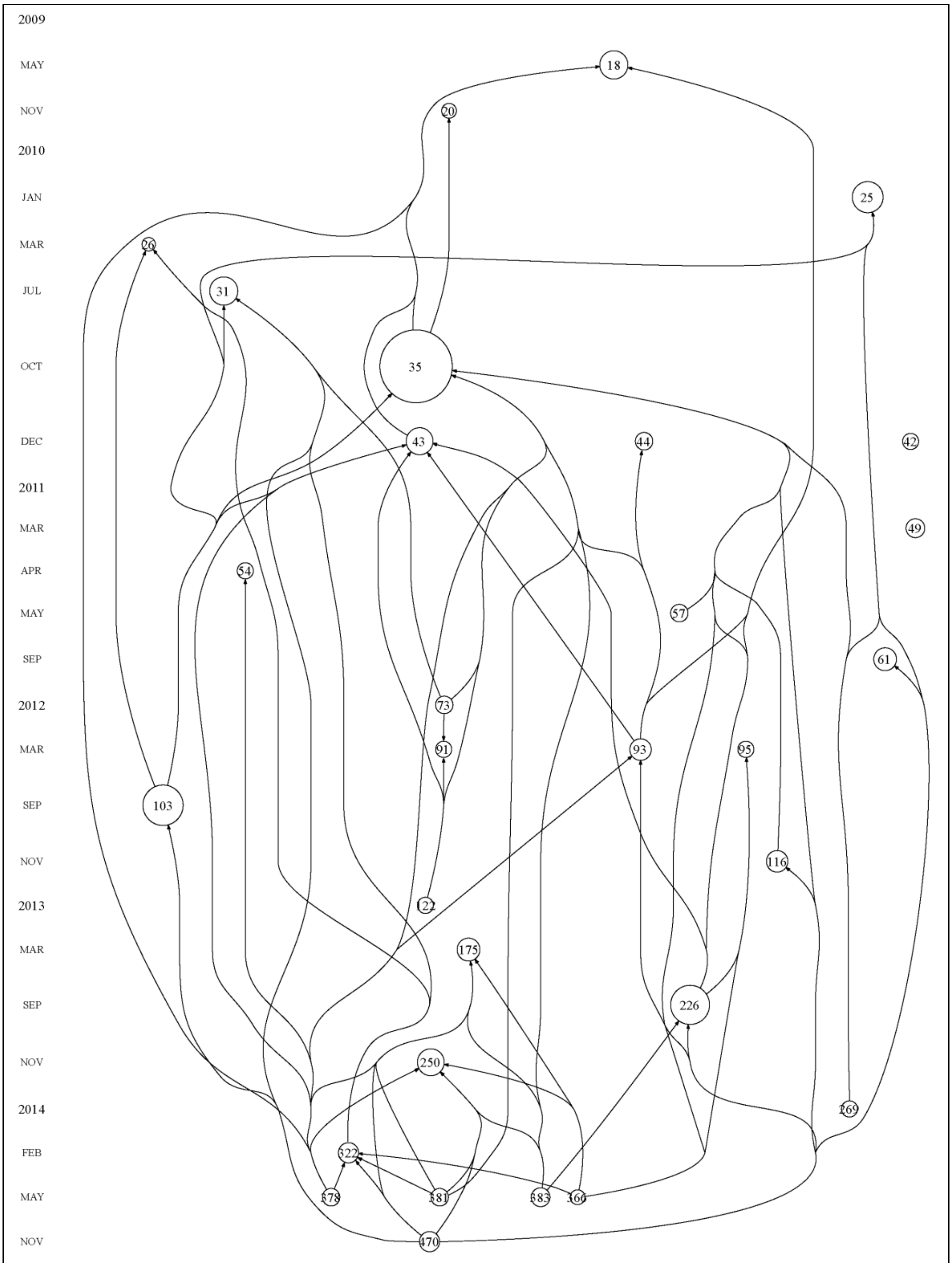


Figure 1. Annual Publication Count and Cumulative Global Citations of IoT Articles



Note: The number inside the vertex correlates to the label number in Table 1.

Figure 2. Algorithmic Historiography of 30 Most Influential IoT Articles

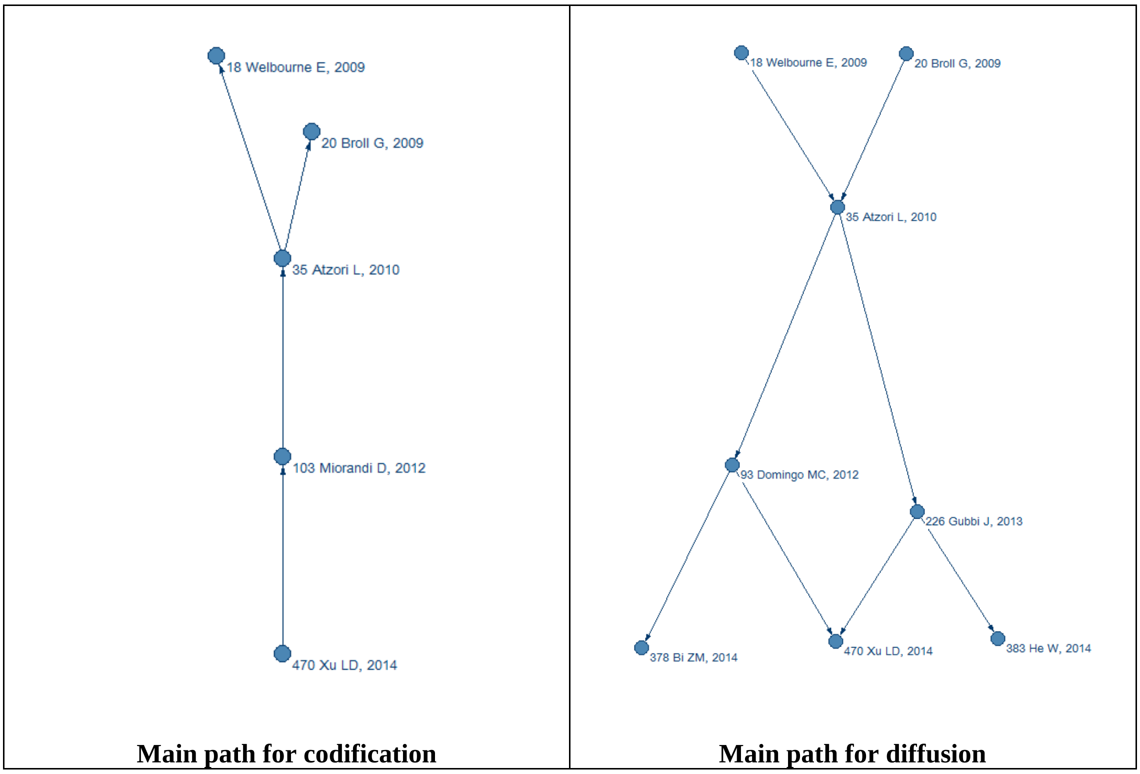


Figure 3. Results of Main-Path Analysis

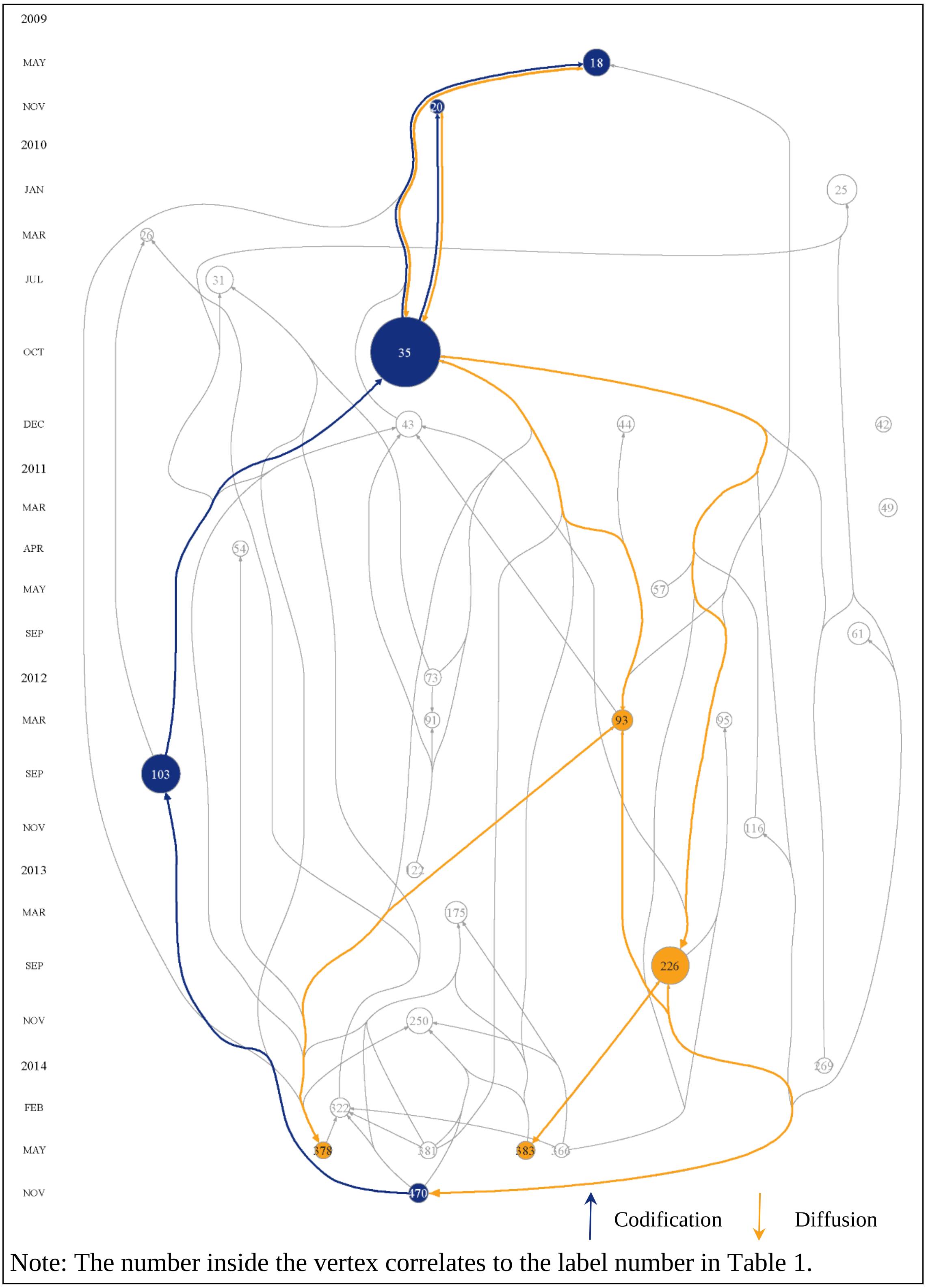


Figure 4. Superimposing the Main-Path Analysis over Algorithmic Historiography