ARTICLE IN PRESS

Technological Forecasting & Social Change xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

journal homepage: www.elsevier.com/locate/techfore

Mapping innovation dynamics in the Internet of Things domain: Evidence from patent analysis

Lorenzo Ardito[a,*], Diego D'Adda[b], Antonio Messeni Petruzzelli[a]

[a] Department of Mechanics, Mathematics, and Management, Politecnico di Bari, Viale Japigia, 182, 70126 Bari, Italy
[b] Department of Information Engineering, Università Politecnica delle Marche, Via Brecce Bianche, 12, 60131 Ancona, Italy

ARTICLE INFO

Keywords:
Internet of Things
Patent analysis
Innovation
Technology evolution

ABSTRACT

The Internet of Things (IoT) is an emerging paradigm in the ICT sector and it is at the center of many current political and economic debates. Scholars, executives, and policymakers are becoming increasingly interested in understanding how to turn the IoT into reality, since various technological constraints (e.g., standardization and interoperability) limit the possibility of realizing an inclusive IoT information network. These constraints are exacerbated by the lack of a clear picture of the innovation dynamics and technology evolution of the IoT. This paper seeks to address this gap by mapping the development of IoT technologies. In particular, we have collected 61,972 IoT patents filed under the Patent Cooperation Treaty in the period 2000–2012. We analyze temporal trends, cross-country dynamics and identity of the applicants. Moreover, we provide insights about the development of the most relevant IoT technologies by looking at triadic patent families.

1. Introduction

In recent years, a new paradigm of information networks has emerged with the aim of expanding the scope of the services that the conventional Web usually provides, namely the Internet of Things (IoT) (Atzori et al., 2010; Feki et al., 2013; Li et al., 2015; Whitmore et al., 2015). The rationale behind the IoT recalls the logic of the Web 2.0, except for the fact that interactions and information processing occur predominantly between physical objects (household appliances, heart monitoring implants, cars, etc.) instead of between people. Accordingly, the denomination of IoT presents the two terms “Internet” and “Things”. The former reflects a network-oriented vision of communication, which entails the use of dedicated hardware, standards, and protocols, just like the Web 2.0 (Karakas, 2009); the latter tends to shift the focus to physical objects rather than to end users, as the “things” to be connected (Atzori et al., 2010). When combined, IoT semantically means a “world-wide network of interconnected objects uniquely addressable, based on standard communication protocols” (Bandyopadhyay and Sen, 2011:50).

Nowadays, the IoT is at the center of the current political and economic debates (European Commission, 2009; Li et al., 2015; OECD, 2015), since it is expected to boost new business opportunities both within and beyond the ICT sector. Some IoT applications and prototype systems have already been launched (e.g., the ZeroG Wireless, Alcatel-Lucent's Touchatag, and Arduino), revealing a growing interest in this domain (European Commission, 2009). Notwithstanding this interest, effective and large-scale systems based on the IoT paradigm are still far from being realized (OECD, 2015). This is primarily due to the technological complexity underlying IoT networks. Indeed, there are many technological issues that have to be simultaneously addressed such as standardization, interoperability, and autonomous communication (Feki et al., 2013). In addition, the fact that the implementation of IoT networks involves different types of technology controlled by multiple organizations spread across various countries (European Commission, 2014; ITU, 2005; Li et al., 2015) engenders additional complexity. Therefore, it is extremely difficult to keep pace with the technological evolution in the IoT domain, and to coordinate and “steer” standardization efforts to ensure interoperability between technological solutions and standards controlled by different and dispersed economic actors (Xu et al., 2014). Accordingly, scholars have argued that obtaining a clear picture of the innovation dynamics and technology evolution underlying the IoT is helpful for gaining valuable insights about the real meaning and functionality of the IoT (Al-Fuqaha et al., 2015:2350). There have only been a few recent studies (Al-Fuqaha et al., 2015; Bandyopadhyay and Sen, 2011; Feki et al., 2013) that have tried to represent the current state of the art of IoT solutions in order to facilitate their definition and identify future trajectories (Xu et al., 2014). Nevertheless, these works have devoted particular emphasis to the scientific theory and engineering design behind those technologies while ignoring the discussions about what technologies

* Corresponding author.
E-mail address: lorenzo.ardito@poliba.it (L. Ardito).

http://dx.doi.org/10.1016/j.techfore.2017.04.022
Received 21 July 2016; Received in revised form 7 April 2017; Accepted 26 April 2017

are actually available for the IoT, who has developed them, what the trends are in their development, and their potential impacts. In other words, despite the importance for social and economic growth, the development of IoT technologies has not yet received a thoughtful examination combining policy and managerial perspectives, contrary to the finer-grained analyses on its technical aspects (Whitmore et al., 2015). In line with this reasoning, this paper aims at filling these gaps by providing a comprehensive picture of the innovative efforts in the IoT domain undertaken over time at the technology, applicant and country levels. Furthermore, we complement our analyses looking at the most relevant patented innovations including insights from a policy and managerial perspective. While providing and testing a theory is beyond the scope of this paper, we provide empirical-based insights about the development of IoT technologies and a comprehensive picture of the innovative dynamics in the IoT domain at different levels of observation.

We collected all the IoT patents over the period 2000–2012 (61,972 patents) filed under the Patent Cooperation Treaty (PCT) by means of a search strategy based on the International Patent Classification (IPC) codes that best reflect patented IoT technologies (UK IP Office, 2014). Then, by leveraging bibliographic information on patents (patent application filing year, identity of the applicants, addresses of applicants, etc.), we describe their development trends looking both at the countries and the organizations mainly engaged in these innovative activities.

The paper is structured as follows. In the next section, we present a brief review of the literature on the IoT and discuss the use of patent data to analyze innovation dynamics and technology evolution. The third section presents the methods and the sample. The fourth section provides descriptive and managerial analyses on the patenting activity trends of IoT technologies. Finally, discussion, implications, and conclusion are presented in the last section.

2. Review of the literature

2.1. The Internet of Things

The logic behind the IoT finds its origin at Carnegie Mellon University in 1982 when a Coke machine was connected to the Internet, hence representing the first physical object in an Internet network.[1] Later, in the early 1990s, the idea of ubiquitous computing (Weiser, 1991) started to gain ground. This concept highlights the possibility of making everything ubiquitously connected, hence affirming the integration and automation of every object, from small household appliances to entire factories. Following this idea, in the late 1990s, the British entrepreneur Kevin Ashton coined the term IoT (Bandyopadhyay and Sen, 2011; Li et al., 2015; Ma, 2011). Although a conclusive definition has yet to be established, this acronym generally refers to a "dynamic global network infrastructure with self-configuring capabilities based on standards and interoperable communication protocols, [where] physical and virtual 'things' in an IoT have identities and attributes and are capable of using intelligent interfaces and being integrated as an information network" (Li et al., 2015:244; Del Giudice, 2016).

Today, the IoT paradigm is of particular interest among managers and policymakers. Indeed, projections reveal that there will be an evergrowing number of devices connected to the Internet, thus supporting the idea that a ubiquitous network of objects can engender industry disruptions and transformations (European Commission, 2014). For instance, machine-to-machine traffic is expected to account for 45% of future Internet traffic (Al-Fuqaha et al., 2015; Evans, 2011). Moreover, Gartner Inc. and ABI Research have estimated that more than 20 billion objects will be connected by 2020,[2] while a study sponsored by the McKinsey Global Institute already reported a percentage increase of 300% of online machines in recent years (Manyika et al., 2013). In turn, great social and economic benefits are expected (Bi et al., 2014; Domingo, 2012). Examples include the development of healthcare (e.g., mobile health and telecare) and manufacturing IoT applications, whose revenues are estimated to be between $1.1 and $2.5 trillion in annual growth by 2025 (Al-Fuqaha et al., 2015; Manyika et al., 2013). Consequently, almost all countries throughout the world have designed policies aimed at fostering R & D efforts in the IoT domain. Among them, some of the most relevant initiatives are the numerous cooperative projects promoted by the European Union (EU) through the IoT European Research Cluster (since 2006), the IT Reform Strategy in Japan (2009), the $800 million investment in IoT solutions by the People's Republic of China, and the allocation of a budget of £40,000,000 by the UK Government to promote IoT technology development (2015) (European Commission, 2009; Li et al., 2015; Xu et al., 2014). Furthermore, interest in the IoT domain by a relevant number of companies is revealed by the formation of the IPSO Alliance, which includes 53 firms such as the Bosch Group, SAP, Intel, and Thales, and the launch of IoT products such as ZeroG Wireless (2006), Arduino (2008), Alcatel-Lucent's Touchatag (2008), and Usman Haque's Pachube (2009) (Bi et al., 2014; European Commission, 2009).

Nevertheless, it is worth mentioning that the actual realization of a ubiquitous information network, as imagined by IoT promoters, is still in its initial stage. Indeed, relevant technological constraints do exist (Al-Fuqaha et al., 2015; Bandyopadhyay and Sen, 2011; Feki et al., 2013). These relate to the wide number of diverse technologies and protocols that are needed in order to implement the IoT paradigm and meet its three main objectives, i.e., more extensive interconnection, more intensive information perception, and more comprehensive intelligent service (Ma, 2011). Specifically, more extensive interconnection requires strong efforts in the refinement and the development of network technologies that allow managing the rising number and variety of devices that will constitute future IoT networks (Gubbi et al., 2013). In addition, in such large-scale heterogeneous networks, challenges related to efficient interconnections cannot be underestimated either, especially those requiring more reliable wireless connections (Atzori et al., 2010; Sheng et al., 2013). Instead, more intensive information perception refers to the necessity of integration and interoperability, since every device has multiple sensors, and the different devices connected together may have diverse sensors and information acquisition routines. In this case, complexity in communication is extremely severe and problems requiring effective communication control technologies emerge (e.g., non-uniformity of data, discontinuity, and inaccuracy) (Ma, 2011). Finally, more comprehensive intelligent service calls for smarter devices (Ehrenhard et al., 2014; Hong et al., 2016) that can automatically exchange and process information. However, this task is difficult without the implementation of new software modeling and data processing solutions (e.g., microcontrollers and microprocessors) that can operate in dynamic conditions (Al-Fuqaha et al., 2015).

The foregoing discussion highlights the technological complexity underlying the IoT, which is exacerbated by the presence of various actors playing different roles in this expansion phase. Indeed, the lack of a clear vision about the current state of the art of IoT technologies makes it difficult to define plans about the most promising IoT networks and to address the above-mentioned challenges. This calls for a more comprehensive picture of the innovation dynamics and technology evolution of the IoT (Bandyopadhyay and Sen, 2011).

[1] See http://www.informationweek.com/strategic-cio/executive-insights-and-innovation/internet-of-things-done-wrong-stifles-innovation/a/d-id/1279157.

[2] See https://www.abiresearch.com/press/more-than-30-billion-devices-will-wirelessly-conne/ and http://www.gartner.com/newsroom/id/3165317.