A Survey on The Internet of Things

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Abstract

Internet of things is a rapidly evolving paradigm with an enormous potential to automate simple human tasks; its enabling technologies bring new improvements to networks which allow us to share information in a way never done before. This paper discusses the enabling technologies and briefly compares them to conclude that an application's requirements matter when electing such technologies. In addition to its enabling technologies, the potential of IoT in many fields will be reviewed and illustrated with a Smart and Connected Community exemplary application called TreSight based in the city of Trento, Italy. There are outstanding issues that need to be addressed with respect to privacy, but moreso with respect to interoperability and resources, part of this paper discusses these issues and the attempts made by the scholarly community to alleviate them.

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Introduction

The Internet of Things (IoT) paradigm has forced radical changes upon our technological needs for the better by offering a promising future that breaks the current limits of information sharing techniques and task automation. Embedded devices are now able to see, hear, think, and even actuate physical tasks by talking to each other, therefore making them the main data producers and consumers [1]. Interesting characteristics of such networks include its comprisement of real world small things that are widely distributed with a limited amount of energy and processing power. What's more stunning, however, is the number of these devices already deployed; they have already outgrown the human population since 2010 [2]. On the other hand, the internet today comprises of humans-on-computers as its end nodes and can be thought of as the internet of computers. As true as that may be, there is an evident transition of network types from the internet of computers to the internet of things with the ultimate goal of allowing the interconnection between the physical and the real worlds.

IoT plays a remarkable role in many fields of applications, namely smart cities, smart home, healthcare, transportation, environment monitoring, energy, and business. Each of these domains will be thoroughly reviewed, as they have the capability of improving quality of life by providing instantaneous solutions to human problems where decision-making is difficult otherwise. IoT also comes with a few challenges of its own; when an embedded device can be placed in a difficult spot for its application it also means it is energy constrained, consequently this also implies that such an embedded device is unable to perform typical security techniques (such as encryption). A paper by B. Martinez et al. attempts to define a power consumption model for IoT devices [4] and is summarized in the Challenges section of this paper. Furthermore, one of the most complex obstacles still outstanding in the paradigm is its interoperability. The number of standards available today far surpases the amount needed to form a complete communications model for IoT networks, and as a result, the evolution of the paradigm is brought to a bottleneck. The consumer base for IoT products is fragmented because the industry sells products with standards that are unable to operate with others. Different standards and protocols stacks are analyzed and compared in a paper by A. Rahman [5]; this paper summarizes said standards in terms of specification, frequency band, maximum signal rate, nominal range, network type, spreading, coexistence mechanism, and power consumption. Conclusively, the various standards may serve for a better use over others depending on the application's requirements. Supplementary to the previous concepts, one of the most important enabling technologies is fog computing. Although cloud computing offers certain merits, fog computing far surpasses it since it provides heavy processing power inside the network while delegating big data tasks to the cloud.

The rest of this paper is organized as follows: the Enabling Technologies section will describe the standards that have empowered the IoT paradigm to progress this far, the Applications section will dwell deeper into the many application fields IoT is capable of enhancing, the Challenges section explains the outstanding issues of IoT and why it is not a simple transition into the paradigm, finally, the Conclusions section will offer my thoughts with regards to the different realization methods available for IoT, as well as closure.

Enabling Technologies

The realization of IoT thus far is owed to the many emerging technologies capable of reproducing a complete communication model specific to IoT. Although there are many variations of such a model, Figure 1 illustrates the general 5-Layer model [6]; a stack of layers that are adequate for the paradigm's requirements:

- Objects layer: composed of sensors that gather information from the surrounding environment. This layer digitizes and transfers the data to Object Abstraction layer
- Object Abstraction layer: secure channels that intermediate between the Objects and the Service Management layers. The standards that form this important layer will be discussed later on in this paper.
- Service Management layer: pairs a service with its requester based on address and names. This allows the programmers to handle the information without worrying about which device it came from.
- Application layer: through interfaces, this layer is capable of providing the relevant data required for specific services.
- Business layer: a management layer that protects a user's privacy, implements decision making processes based on big data, and generates reports. This layer is usually hosted in a powerful machine at the edge of the network due to its complexity.

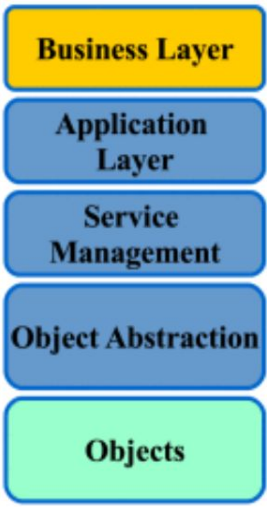

Figure 1. The 5 Layer protocol [6]

The Object Abstraction layer has many standards for alternatives. It is currently a competitive environment where companies and organizations advocate their own standards, bringing the evolution of the entire paradigm to a bottleneck; this issue will be discussed more thoroughly in the Challenges section. A. B. A. Rahman makes a clear comparison between some of the most relevant standards with regards to specification, frequency band, maximum signal rate, nominal range, network type, spreading, coexistence mechanism, and power consumption [5]. ZigBee, Bluetooth LE, Z-Wave, NFC, and Wifi are compared in Table 1. Wifi is technically called the IEEE 802.11 standard and works by defining the Physical (PHY) and Medium Access Control (MAC) layers to provide wireless communication in two modes: ad-hoc (peer-to-peer) and infrastructure (peer-to-AP). It transmits data using the Industrial, Scientific, and Medical (ISM) band. Although being capable of transmitting large amounts of data and offering a wide nominal range, it is often discarded as an option for IoT applications due to its overwhelming power consumption. NFC's physical layer is based on the ISO14443 standard, which allows for a safer, more convenient, and faster form of data transfer between phones. Unlike the other standards, Z-Wave uses the lowest amount of power, offers an outstanding nominal range, and is intended for home automation systems. However, it is limited by its star-topology where only the master is allowed to transmit information. Bluetooth Low Energy (LE) is similar to Bluetooth but is designed for ultra low-power applications, and is among the most attractive standards due to its maximum signal rate, nominal range, power consumption and the use of the ISM band. Finally, ZigBee is based on the IEEE 802.15.4 standard; it is a popular option for energy constrained devices and builds a complete network protocol stack for Wireless Sensor Networks (WSNs).

Standard	ZigBee	Bluetooth LE	Z-Wave	NFC	Wifi
IEEE Spec	802.15.4	802.15.1	ITU-T	ISO 13157	802.11a/b/g
Frequency band	868/915 MHz; 2.4 GHz	2.4-2.5 GHz	908.42 MHz	13.56 MHz	2.4 GHz; 5 GHz
Max signal rate	250 Kbps	305 Kbps	40 Kbps; 100 Kbps	424 Kbps	54 Mbps
Nominal range	10 m	~50 m	~30 m	~5 cm	100 m
Network type	WPAN	WPAN	WPAN	P2P	WPAN/P2P
Spreading	DSSS	FHSS	FHSS	GSMA	DSSS, CSK, OFDM
Modulation type	BPSK (+ ASK), O-QPSK	TDMA	GFSK	ASK	BPSK, QPSK, COFDM, CCK, MQAM
Coexistence mechanism	Dynamic frequency hopping	Adaptive frequency hopping	Adaptive frequency hopping	RFID	Dynamic frequency selection, transmit power control (802.11h)
Power consumption	~40 mA	~12.5 mA	2.5 mA	~50 mA	~116 mA (at 1.8 V)

Table 1. A comparison of the ZigBee, Bluetooth LE, Z-Wave, NFC, and WIfi standards [5].

These standards exceed in certain aspects over others; Z-Wave outperforms ZigBee in power consumption, ZigBee is preferred for WSNs over Z-Wave for its topology, Bluetooth LE has an outstanding nominal range. Conclusively, the various standards may serve for a better use over others depending on the application's requirements.

Furthermore, technological advancements have been made in the fields of Big Data processing. IoT is a rapidly advancing field; initially a solution offered for processing colossal amounts of historical data produced by the billions of heterogeneous devices was the Cloud [13], however this idea has been technologically surpassed by Cisco's fog computing (also known as edge computing) [14]. Fog computing extends cloud computing by bringing computational and storage services to the edge of the network, while Big Data processing tasks that usually take months to complete are delegated to the cloud for processing [15]. These resource-intensive computers (which are close to the network) allow for a new breed of real-time low-latency applications. More generally, the nature of fog computing grants the possibility of new applications and services under the umbrellas of connected vehicles (CV), smart grid, smart cities, and WSNs.

Applications

The impact of the Internet (when it was a brand new concept) imposed heavy radical changes; it significantly changed the world in many aspects. Similarly, IoT has the potential to change the world again by offering new opportunities to many domains, namely smart cities, smart home, healthcare, transportation, environment monitoring, energy, and business. Humans now have the ability to automate trivial tasks such as finding a parking spot, to complex tasks where human-decision is difficult, such as detecting potential vehicular collisions. This section dwells deeper into the many application fields IoT is capable of enhancing, and conclude it by providing a prime example of a Smart and Connected Community application.

I. Smart Home

Smart Home applications aim to make a lifestyle more convenient inside the perimeters of the house. Appliances and systems such as automatic dishwashers or Heating-Ventilation-and-Air-Conditioning (HVAC) no longer need extensive human interaction but instead provide remote controls. Adding to the already existing convenience is the fact that commercial home automation systems typically integrate a large portion of our technological needs within them. Typically, a home security and automation system has the ability to monitor perimeters, open and close windows depending on the weather, provide security mechanisms such as PINs or biometrics to authenticate a user, to name a few. However, such systems also have the capabilities to monitor the non-criminal elements such as air quality, potential floods, HVAC, etc. The sensors that make up these systems collect data from their surroundings and report to a central control unit using a star topology [12]. The central control unit is employed because it offers more processing power, which allows for more complex decisions to be made in terms of achieving a task related to the well-being of a house.

II. Healthcare

Healthcare applications have significantly improved through the use of smart things connected to patients that need thorough care and analysis. The IoT is used by clinical care to monitor physiological statuses of patients through sensors by collecting and analyzing their information and then sending analyzed patient’s data remotely to processing centers to make suitable actions [6]. A simple yet obvious example can be the monitoring of a patient's heart rate through the use of a smart wristband; the information collected is uploaded and stored at a nearby unit through the use of Wifi, and later on analyzed by the clinic to determine any anomalies for that given period with respect to the patient’s condition. Furthermore, the wristband can be used to send alerts to a nurse if the patient’s heart rate crosses a threshold.

III. Transportation

Intelligent Transportation Systems (ITS) aim to facilitate the mobility in urban centers. Certain Vehicular ad-hoc network applications have initiatives focused on ITS to reduce congestion and increase security for citizens [7]. A. Al-Fukaha’s paper [6] explains how ITS is composed of four major components and are sequentially contrasted with the Wireless Access and Vehicular Environments (WAVE) standard reviewed in [8] by R. A. Uzcategui et al.:

- Vehicle subsystem: a GPS, RFID reader, On Board Unit (OBU), and communication. An example from the WAVE standard is the OBU component of the network
- Station subsystem: roadside equipment. WAVE integrates Roadside Units (RSU), installed in light poles, traffic lights, road signs, etc.
- ITS monitoring center: management services. This can be thought of as the WAVE management entity (WME), a set of management functions that define the networking services.
- Security subsystem: a layer introduced within the WAVE protocol stack is the security services blocks.

These four components are capable of providing services to applications, such as those that monitor for accidents; vehicles notify the RSUs about the accidents, then the RSUs upload this information to the stop light schedule computing node.

IV. Environment Monitoring

Environment Monitoring can help humans understand the Earth at a deeper level. Ramanathan et al. present *Suelo,* an embedded network sensing system for soil monitoring. This system is aimed at alleviating the issue where scientists do not possess the ability to collect the high-resolution data required to fully understand the ecosystems within the soil, which play a critical role in the Earth’s water and nutrient cycles [9].

V. Energy

Intelligent energy management and distribution systems improve the consumption of energy in a wide variety of human-populated areas. As stated by M. Yun and B. Yuxin [10], “The principal characteristics of smart grid include self-healing, mutual operation and participation of the users, perfect electricity quality, distributed generations and demand response, sophisticated market and effective asset management.” Consider a set of solar panels attached to a home’s rooftop; the solar energy obtained can reduce the need of energy from the city’s main power grid, and could possibly even give back to it, therefore forming a grid that not only sends energy to a home but also receives surplus energy from it [11].

VI. Business

Business can benefit from IoT applications that reduce costs in warehouse logistics and service industries. Furthermore, IoT can improve the quality of service of those businesses that require quick and convenient information by querying a IoT database of non-trivial information (ex: lost and found objects) [1]. A more thorough example is as follows: consider a store that depends on complex machinery to maintain its production line; through smart sensors the business could predict the end of life of their machines, or even foresee possible issues that could disrupt production.

VII. Smart Cities

Smart City (SC) applications offer a more convenient lifestyle for residents from a public perspective. A more sophisticated form of this domain is Smart and Connected Communities (SCC) which improves the lifestyle in terms of livability, preservation, revitalization, and attainability [3]. SCC has the ability to commemorate the cultural and natural heritage of a community, and it also intents to satisfy the needs of the present generations without endangering the needs of the future ones.

TreSight, a case study

The case study TreSigh analyzed by Y. Sun et al. in [3] is an IoT application that uses Big Data to provide smart tourism. It is a Mobile Crowdsensing (MCS) application based in the small city of Trento, Italy which has a high level of cultural and environmental heritage. The application requires people to wear wristbands with sensors that report to hotspots located near restaurants, museums, and typical tourist locations. A tourist may download an application on their phone which simply collects information about the suitable and convenient spots for them to visit; this entails in the application recommending spots that have been visited by the most wristbands and obtained the most commendations. At its heart, TreSight uses Big Data to deeply analyze the information collected (preservation and revitalization), understand its social and external aspects (livability; such as weather), and predicts/prevents tourist spots (sustainability).

Challenges

Despite the many efforts taken to achieve an ideal IoT framework, there are still outstanding issues that need to be addressed. The privacy and security of an IoT network cannot be taken lightly when designing an application; it is the direct result of the Objects layer’s limited resources. Furthermore, a lack of interoperability between the many protocols has brought the evolution of the paradigm to a bottleneck. This section further discusses these two general issues.

I. Interoperability

The interoperability aspect of IoT networks should be considered when defining the standards that form the Object Abstraction layer. These standards are proprietary to companies and organizations whose objective is to advocate their own and beat those of their competitors. Therefore, this lack of integration between said standards clearly forms a barrier hindering the evolution of IoT by fragmenting the consumer base for IoT products; such a phenomenon occurs when the industry sells products with standards that are unable to operate with others. Earlier in this survey, it was stated how the decision to use a certain standard depends on the application's requirements, and while this holds true today, the ultimate interoperability goal entails to either: 1) have these standards be able to communicate with each other, or 2) elect a single standard which exceeds in all aspects. The latter option could become a reality through Bluetooth LE, which as discussed, dominates over other standards in various qualities.

II. Privacy and Security

Privacy and security concerns are a direct consequence of the Objects layer limited resources. Embedded devices lack the energy and processing power to perform classic security techniques such as encryption, ultimately leaving said devices prone to hacker attacks; a hacker could compromise a sensor of a home security system, perform a man-in-the-middle attack, eavesdrop on the information available to that sensor, and eventually deduct a best time to break inside the home [16]. To alleviate these issues, the scholarly community has undertaken research at the root of the problem: energy-constraints at the Objects layer. A paper by B. Martinez et al. attempts to define a power consumption model for IoT devices [4]. Despite the fact that energy-dimensioning and energy-harvesting are a difficult task, the model presented in this paper successfully performs a system-level analysis on the energy consumption of wireless sensor nodes on the three following levels:

- Acquisition: the energy required to collect data from the surrounding environment. This amount depends on whether said data is acquired through event-driven mechanisms or simply by sensing the environment at regular intervals.
- Networking/Communication: the energy needed to transmit the collected data to the rest of the network. Some of the factors that affect this number include radio power, retransmission, and spread.
- Processing: the energy required to perform arithmetic tasks. One of the factors included in B. Martinez's formula are counters mapped to the microprocessor's operations.

Conclusions

The rapidly evolving concept of IoT is forcing radical changes as of right now, and will continue to do so for the unseeable future. The paradigm aims to improve the quality of life of humans in many by connecting billions of heterogeneous real world small things into networks that interconnect the physical world with the virtual. Ultimately, IoT has the potential to automate everything around us, from the most trivial human tasks, to the more complex ones where decision-making is difficult otherwise. There are many domains that are positively affected by the introduction of IoT, namely smart cities, smart home, healthcare, transportation, environment monitoring, energy, and business. This paper reviewed each one of these domains and provided realistic examples of possible applications. Moreover, IoT-enabling technologies were discussed and briefly compared in terms of specification, frequency band, maximum signal rate, nominal range, network type, spreading, coexistence mechanism, and power consumption. Finally, the transition from the internet of computers to the internet of things is not quite as simple. This paper considered the open issues which are currently hindering IoT's full potential, and offered a non-trivial solution to the energy-constraint problem offered by the academic community. The continued efforts undertaken by researchers, vendors, and organizations is crucial for the IoT paradigm to realize its full potential. This survey provides a high level representation of where IoT currently stands, and hopes to serve as an informational source to practitioners looking to gain better knowledge of the subject.

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Works cited

[1] Y. Qin, Quan Z. Shen, Nickolas J.G. Falkner, et al. “When things matter: A survey on data-centric internet of things,” *Egyptian Journal of Medical Human Genetics*, 11-Feb-2016. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1084804516000606. [Accessed: 30-Aug-2018].

[2] D. Evans, “The Internet of things: How the next evolution of the Internet is changing everything,” CISCO, San Jose, CA, USA,White Paper, 2011.

[3] Y. Sun, H. Song, A. J. Jara and R. Bie, "Internet of Things and Big Data Analytics for Smart and Connected Communities," in *IEEE Access*, vol. 4, pp. 766-773, 2016.

[4] B. Martinez et al., "The Power of Models: Modeling Power Consumption for IoT devices", IEEE Sensor J., pp. 5777-5789, 2015.

[5] A. B. A. Rahman and R. Jain, “Comparison of Internet of Things (IoT) Data Link Protocols,” *Nation-State Cyber Espionage and its Impacts*. [Online]. Available: https://www.cse.wustl.edu/~jain/cse570-15/ftp/iot_dlc/index.html. [Accessed: 30-Aug-2018].

[6] A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari and M. Ayyash, "Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications," in *IEEE Communications Surveys & Tutorials*, vol. 17, no. 4, pp. 2347-2376, Fourthquarter 2015.

[7] G. L. Junior, R. P. C. d. Nascimentos, M. A. R. Dantas and D. D. J. d. Macedo, "A Platform for Vehicular Networks in the Cloud to Applications in Intelligent Transportation Systems," *2017 IEEE 26th International Conference on Enabling Technologies: Infrastructure for Collaborative Enterprises (WETICE)*, Poznan, 2017, pp. 101-106.

[8] R. A. Uzcategui, A. J. De Sucre and G. Acosta-Marum, "Wave: A tutorial," in *IEEE Communications Magazine*, vol. 47, no. 5, pp. 126-133, May 2009.

[9] Ramanathan N, Schoellhammer T, Kohler E, Whitehouse K, Harmon T, Estrin D., “Suelo: human-assisted sensing for exploratory soil monitoring studies”. In: *Proceedings of the seventh international conference on embedded networked sensor systems (SenSys)*. Berkeley, CA, USA: ACM; 2009. p. 197–210.

[10] Miao Yun and Bu Yuxin, "Research on the architecture and key technology of Internet of Things (IoT) applied on smart grid," *2010 International Conference on Advances in Energy Engineering*, Beijing, 2010, pp. 69-72.

[11] K. Ramakrishnan, “From smart meter to smart grid – looking at real world examples,” *Ericsson.com*, 04-Nov-2014. [Online]. Available: https://www.ericsson.com/thinkingahead/the-networked-society-blog/2014/11/04/looking-real-world-examples-smart-meters-smart-grid/. [Accessed: 31-Aug-2018].

[12] “Selecting correct cabling topology - Ring vs Star vs Bus,” *Home*, 14-Dec-2015. [Online]. Available: https://www.ad-net.com.tw/selecting-correct-cabling-topology-ring-vs-star-vs-bus/. [Accessed: 16-Jul-2018].

[13] Alessio Botta, Walter de Donato, Valerio Persico, Antonio Pescapé, “Integration of Cloud computing and Internet of Things: A survey,” *Future Generation Computer Systems* Volume 56, 2016, Pages 684-700.

[14] “Fog Computing and the Internet of Things: Extend the Cloud to Where the Things Are.” (2015). [white paper] USA: *Cisco*. Available at: https://www.cisco.com/c/dam/en_us/solutions/trends/iot/docs/computing-overview.pdf [Accessed 2 Sep. 2018].

[15] F. Bonomi, R. Milito, J. Zhu, S. Addepalli, “Fog computing and its role in the internet of things.” *Proceedings of the first edition of the MCC workshop on Mobile cloud computing*, 2012, Pages 13-16.

[16] A. Jacobsson, B. Carlsson, and M. Boldt, “A risk analysis of a smart home automation system,” *Future Generation Computer Systems*, vol. 56, pp. 719–733, Sep. 2015.