INFORMATYKA I MATEMATYKA

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INTERNET RZECZY I JEGO POTENCJALNY WPŁYW NA BIZNES

[**słowa kluczowe**: Internet Rzeczy, konfiguracje systemów, obliczenia w chmurze, modele biznesowe]

Streszczenie

W artykule przedstawiono powstawanie Internetu Rzeczy (IoT), jego główne właściwości, włącznie z rolą czujników i systemów łączności, połączenia z chmurą, jak również wpływ na powstawanie nowych modeli biznesowych. Omówiono również konfiguracje systemowe IoT, z przykładami rozwiązań technicznych i potencjalnymi korzyściami dla gospodarki. Ponadto, naszkicowano główne wyzwania i czynniki ryzyka wynikające z wprowadzenia tej technologii, włączając zagadnienia ochrony danych, prywatności i problemy prawne. Artykuł koncentruje się na omówieniu podstaw tej technologii i jedynie pobieżnie odnosi się do bardziej zaawansowanych problemów technicznych lub badawczych.

INTERNET OF THINGS AND ITS POTENTIAL IMPACT ON BUSINESS

[**keywords**: Internet of Things, system configurations, cloud computing, business models]

Abstract

This paper discusses the emergence of the Internet of Things (IoT), its major technical characteristics, including sensors and device connectivity, merging with the cloud, as well as its impact on creating new business models. IoT's configurations are presented, with examples of basic technical solutions, and benefits for the economy are discussed. In addition, several challenges and risks involved with the introduction of this technology are outlined, such as security, privacy and legal issues. The paper's emphasis is on discussing the background of the technology, so the depth of discussing technical aspects and addressing the research issues is limited.

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Introduction

The Internet of Things (IoT) has emerged imperceptibly, as a separate term in computing probably at the end of previous century, but over the last decade or so, it has seamlessly conquered the world to the extent that now it is considered disruptive to many established industries. It became a ubiquitous reality today, penetrated various aspects of business, and conservative estimates anticipate that there will be some 20 billion devices on the Internet of Things by the year 2020, so within our direct reach. Even more so, IoT's growth projections are astounding – with 26 billion connected devices connected by the year 2026 according to Gartner. Other projections estimate an IoT market growth to be well over $1 trillion by 2020.

IoT's application areas are already numerous and include not only, as one would immediately say, smart homes and cities, but many industries, traditional or not:

- health care (obtaining and storing patient data to allow patient monitoring online and in real time),
- retail (advantages to consumers and, at the same time, optimization of sales),
- vehicles of all kinds (traffic and route optimization; maintenance scheduling),
- agriculture (where remote control of growing conditions helps maximize the crops and profit),
- manufacturing (industrial automation and maintenance),
- pharmaceuticals (improving drug quality and patient outcome),
- textile (to analyze the machine behavior and proactively take decisions to improve the quality and productivity),
- energy and utilities (improvements in energy production, efficiency and distribution),
- gas and oil (new operational insights by analyzing vast sets of data at the source),

- environment (monitoring air and water pollution, weather prediction, etc.),
- commercial aviation and aeronautics (especially with the advent of unmanned aerial vehicles that can make autonomous decisions independent of humans).

In this view, there are multiple questions, which come to mind. How is the Internet-of-Things changing business and industry? What will be the effect of IoT technologies on business operations, productivity, effectiveness and efficiency? Can the inherent risks, which it brings, such as security, be mitigated, in a way that business and industry would openly embrace the new opportunities? These are among a few research questions explored in this paper. It must be added, though, that the paper's emphasis is on discussing the background of the technology, rather than addressing details of potential disruptions it may cause, so the depth of discussing technical aspects and addressing the research issues is limited.

The rest of the paper is structured as follows. The next section gives an architectural overview of the IoT, which is followed by a more detailed section on the Device Things Layer, followed in turn by a section on Merging with the Cloud. This is followed by sections on IoT induced Business Models and Impact on the Supply Chain. Then, challenges and business risks are mentioned in a short section, which is followed by a conclusion.

IoT Architectural Overview

Thus, what exactly is the Internet of Things (IoT)? The IoT does not appear to have a single, widely adopted, definition. Many people attempted to define it and nearly all such definitions are acceptable, once they refer to a broad array of interconnected, digitally enabled, devices forming a network with some intelligence built into it. However, one particular definition should appeal more to the professionals, since it comes from an engineering society and reads as follows [1]-[2]:

> Internet of Things (IoT) is a system consisting of networks of sensors, actuators, and smart objects whose purpose is to interconnect "all" things, including everyday and industrial objects, in such a way as to make them intelligent, programmable, and more capable of interacting with humans and each other.

This is just one of many definitions, but gives a good idea what the IoT is considered to be according to professional circles. A similar definition coming from the same document [2], says this in slightly different words:

> IoT refers to any systems of interconnected people, physical objects and IT platforms, as well as any technology to better build, operate, and manage the physical world via pervasive data collection, smart networking, predictive analytics, and deep optimization.

Even though there is no single, widely adopted, definition there are a number of characteristics, which can be attributed to the IoT. The most important of those are its architectural components, which (even though this is not an exhaustive list) can be enumerated as follows:

- smart devices at the user end,
- communication infrastructure to facilitate connectivity,
- computing cloud to provide data storage,
- analytics at the cloud level, to assist in data interpretation.

As can be viewed in Fig. 1, adopted from [3], there are multiple devices („things", some of them smart, but some of them dumb) at the user end, a communication infrastructure with devices accessing the cloud directly but also via intermediaries, such as local gateways, and service providers in the cloud equipped with appropriate analytical tools. The real issues are, of course, much broader but limiting the discussion in this section only to technical components, one can point out to several different aspects and ask a number of questions of interest:

- Understanding what are the critical constituents of the IoT?
- Defining what are the principles of building Internet connected devices with data sharing capabilities?
- Realizing who are IoT's stakeholders, a part of which translates into defining what are the actual and potential application areas?
- Anticipating what are the challenges of this new, untamed technology?

What are the critical constituents of IoT may not be that well perceived and understood, since this requires some generalization of IoT existing concepts, and this is difficult to do, because of the fluid nature of the technology. In a recent NIST report [4], Jeffrey Voas outlines these constituents, calling them the primitives, that is, minimal elements of which the IoT is built. In his generalization concepts, the IoT is an instance of the Network of Things (NoT), and its primitives are:

- sensor, a rather ubiquitous and well understood component; in Fig. 1 it is viewed a Device Thing, where a Device Thing is broader and may include, in particular, actuators and intelligence,
- aggregator, which serves the purpose of collecting and preprocessing data from various sources (sensors); in Fig. 1, it can be a Gateway,
- communication channel, a notion rather straightforward – anything that conveys data; in Fig. 1, channels are represented by arrows,
- eUtility, which means external utility, that is, a service entity; its equivalent in Fig.1 is marked as Service Provider,
- decision trigger, that is, an entity, which creates the final result; there is no direct equivalent of this entity in Fig. 1, because a decision trigger involves analytics, which is a crucial element of the IoT at the cloud (Service Provider) level, while the diagram itself represents abstraction of IoT's physical components.

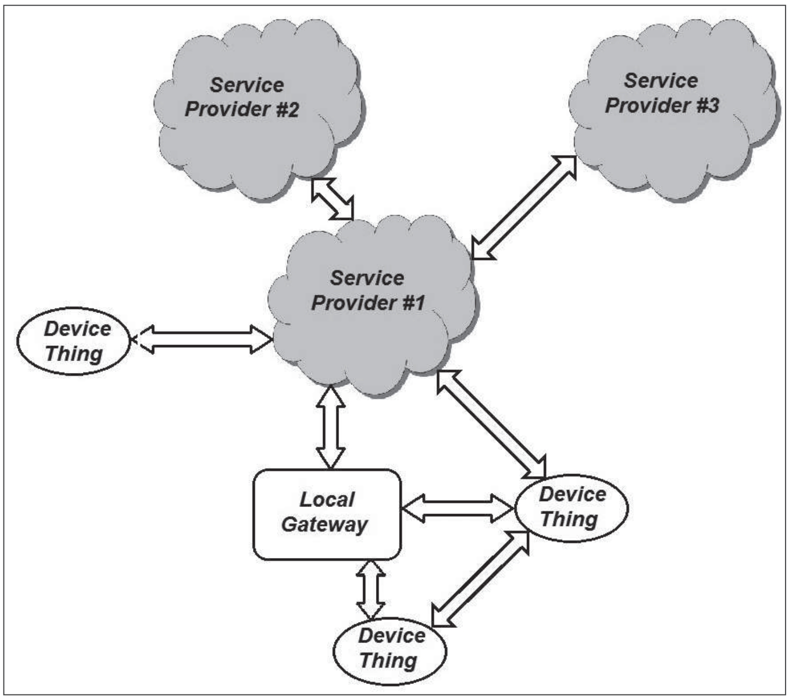

Fig. 1. Overall Architecture of the Internet of Things

It is important to add, at this point, that given individual components of each layer in Figure 1 have existed for decades, how was this all possible that the IoT was conceived very recently rather than decades ago? The answer is in the, so called, enablers. In other words, there must be some necessary artefacts or events or just innovative concepts coming into place, for the existing technologies to convert and create a new quality. In the case of IoT, different authors refer to different enabling factors, but all of them mention the following three decreases in pricing over the last decade, as critical and essential reasons of the emergence of IoT [5]:

- cheap sensors, cost of sensors has gone down from $1.30 to $0.60 per unit,
- cheap bandwidth, the cost has declined by 40 times,
- cheap processing, which has declined by 60 times.

Certainly, one could add to this list a constant decline in the cost of storage, which has been decreasing exponentially over the last three decades to drop a few years ago below 10 cents per gigabyte.

Device Things Layer

Figure 2, adopted from [6], shows from a different angle, how the IoT definitions map on the practical architecture of the Internet of Things. To start with, there are always multiple data sources, these „things", as they are called. They are represented in Figure 1 by instances of:

- pressure transmitters,
- lighting system,
- coffee maker,
- washing machine,
- dishwasher,
- guitar,
- car,

and many more, including comfort, weather and even laptop, although those are normally not considered a part of the lowest layer. One particular caveat is that in many papers and presentations, this layer is represented just as a sensor layer.

This is not exactly correct, since -- as the diagram in Figure 2 shows -- the layer of „things" may include all sorts of data sources but also data sinks, that is, devices that are just recipients of data, for example, for display or control:

- light emitting diodes (LED's),
- LCD displays,

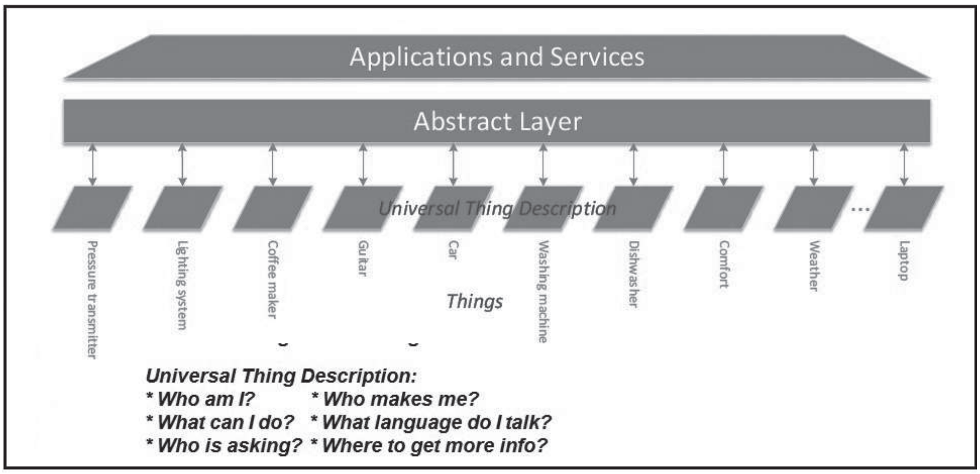

Fig. 2. IEEE P2413 IoT Application Framework [6]

- street lights,
- door locks,
- relays,
- rotors and motors,
- 3D printers,
- even speakers, etc.

So, one has to think about this layer as a device layer, which includes sensing and actuating devices, that is, data sources (senders) but also data sinks (recipients). These device things, as it is clear from both sample lists above, may have various knowledge about themselves and the surrounding world, that is, rudimentary intelligence, which is referred to in Figure 2 in a number of questions:

- Who am I?
- Who makes me?
- What can I do?
- What language do I talk?
- Where do you go to get more information?
- Who is asking?

The devices themselves may be useful on their own, operating in isolation, but the key issue is to make them operate within a bigger system, that is, given some important conditions are met, to create an Internet of Things. These conditions are reflected in Figure 2 by an Abstract Layer and the top layer named

Applications and Services. An Abstract Layer is just an intermediary between Device Things (that is, sources and sinks of data), and services (that provide ultimate use of data and facilitate decision making).

Thus, in an architectural sense, an Abstract Layer must consist of the communication infrastructure as well as the servers, which would host the services. The „communication infrastructure" is the Internet itself, but can be any network, and the „servers" are just computers embedded in the cloud. Then, the Applications and Services layer becomes an „intelligence" layer, offering related data processing capabilities, analytics, and decision support.

From the technical standpoint, to develop the Internet of Things at the Device Thing (sensor and actuator) level, it is important to understand building individual components and programming them, with intricate knowledge of the communication infrastructure. Since the focus of this paper is on outlining higher level business issues and implications of the technology, herewith we only refer the reader to the programming literature [7]-[9], which is now emerging and discusses how to build and program these devices practically and how to provide their connectivity. The low-level network communication, although also important, is not discussed here either and the reader is referred to the available standards on Bluetooth, Zigbee, RFID (Radio Frequency ID) and NFC (Near Field Communication).

Merging with the Cloud

Given the large variety of sensors that can be deployed ubiquitously in an IoT system, a large volume of data may be generated at a high velocity. These exactly are the three challenges in any Big Data application [10]: Variety, Velocity, and Volume. To address these challenges, many technologies have been introduced, for example NoSQL databases [11]. With the rapid growth of cloud computing, many of the Big Data challenges have been effectively addressed. According to the National Institute of Standards and Technology (NIST) [12], „cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction." In the past decade, cloud computing has introduced a paradigm change to computing. The two front runners in providing cloud computing, the Amazon Web Services (AWS) [13] and Microsoft Azure [14] offer, respectively, fifty-five and fifty-nine different services as of the time of this writing.

An essential service in the cloud is called auto-scaling. This service allows software engineers to use computer programs to dynamically provision resources, such as computing power and storage space based on the current demand. This avoids resource underutilization as well as service degradation by programmatically turning off or on virtual machines based on the demand. In an IoT system, auto-scaling can address fluctuating inputs from the sensors. The more/less the input from sensors, the more/less the provisioned resources. The cloud vendors also provide many Platform as a Service (PaaS) tools [12], which abstract the details of installing, configuring, and updating software environments so that the developers can concentrate on the actual business logic. It appears that many such PaaS tools can be utilized in an IoT application.

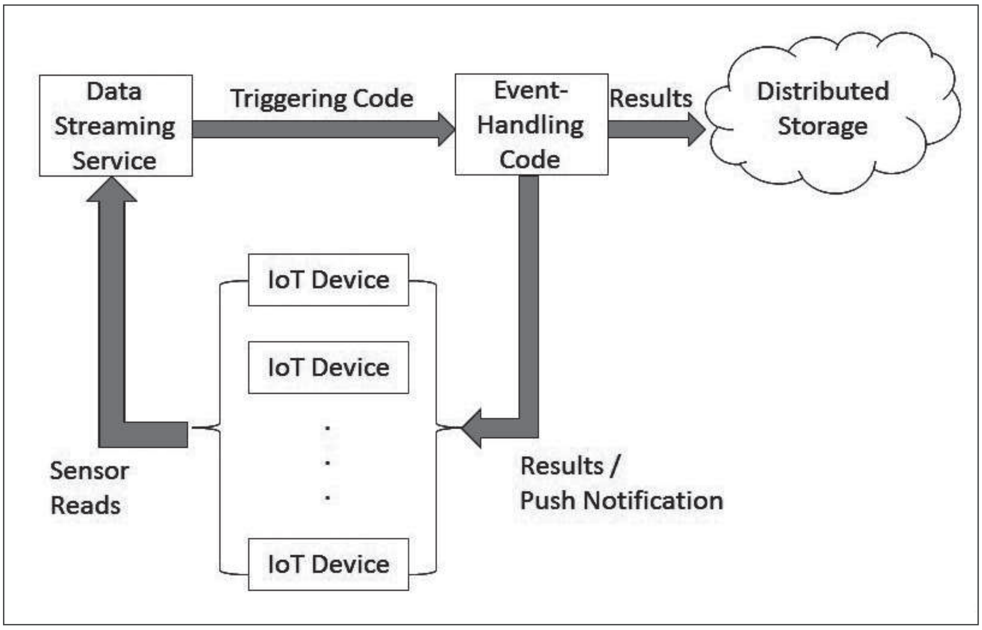

Fig. 3. Example of Using Cloud Services to Build an IoT System

Both Amazon Web Services (AWS) and Microsoft Azure offer services that support data streaming, push notifications, event-driven architecture, which can be used in developing a software system to respond to individual sensor reads. As shown in Figure 3, the devices are linked via the Internet to the data streaming service which then invokes different programs to respond to different events. At last, the result can be stored in a distributed storage system or pushed to other devices. Using these services, software engineers only need to focus on how each read should be handled, without worrying about networking, programming dependencies, runtime environments, data consistency, synchronization, and dynamic provisioning. Cloud vendors even provide higher-level PaaS services for developing IoT applications by grouping individual smaller PaaS services. Two such examples are AWS IoT [13] and Microsoft Azure IoT Suite [14]. Figure 4 shows the design of an IoT software architecture for health care, developed by Royal Philips based on the AWS IoT [15].

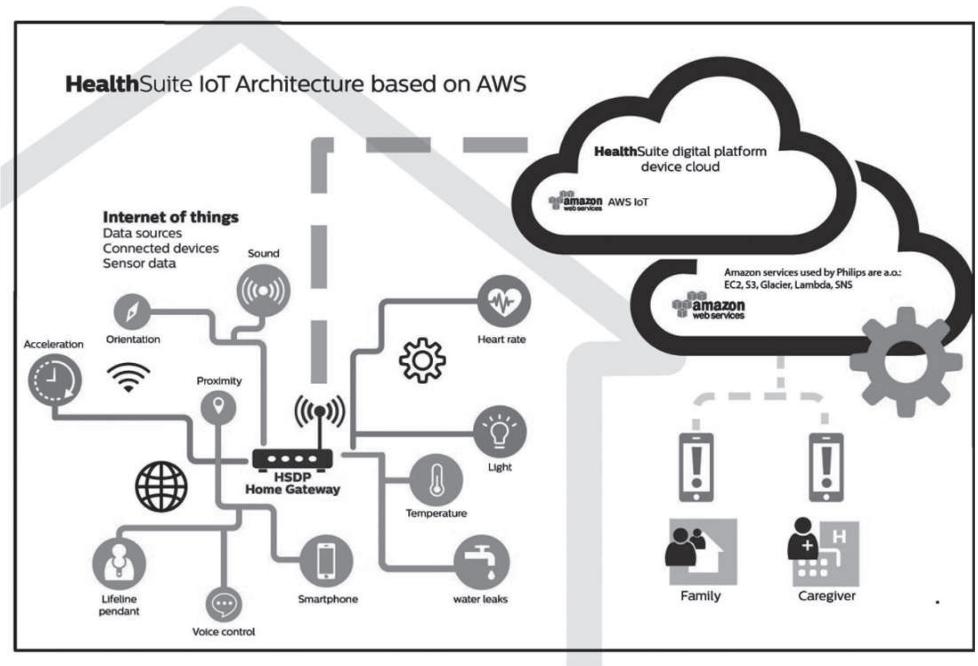

Fig. 4. Philips HealthSuite IoT Architecture based on AWS [15]

IoT Consequences – New Business Models

All this being said, that is, now when we have a big picture of the IoT, a question that may be asked is: What are the real and potential impacts of the emergence of the Internet of Things on the way people, companies and governments do business? Because of "the possibility of generating data, collecting it, and then using this information to create new services" [16], the Internet of Things is challenging and impacting the traditional business models.

While there are already appearing books [17]-[19] discussing business consequences of the emergence of this technology, it is not exactly clear what these consequences are. One thing seems certain, though, that this is a disruptive technology, that is, it has a potential to change the way people and companies are doing business, and as a result, some companies will emerge as winners and some will go under as there will be winners and losers, just like in the immediate past:

- in the first wave of the Internet age, the emergence of world wide web radically changed the commercial world by introducing a new business model of e-commerce (the rise of Amazon, eBay, etc.), because of a radical change in connecting people (consumers) with companies,
- in the second wave of the Internet age, the emergence of social networks radically changed the world of advertising (the rise of Facebook, Twitter, etc.), because of a radical change in connecting people with other people.

The Internet of Things can be viewed as the Third Wave of the Internet, because of a radical change in connecting people with devices, whose consequences will be huge but the exact impact is not yet known. Who will be the big winner? Google? Microsoft? Apple? Someone else likely to emerge? So, this is the subject of intensive research, to study not only the architecture of the IoT but also the potential consequences of IoT developments.

The traditional business model of manufacturing and selling a product, and potentially ending a connection with consumers to provide services and therefore generating additional revenue stream, is being challenged by the new technology. New business models enabled by smart, connected products can create a substitute for product ownership, reducing overall demand for a product, increasing customer satisfaction and placing less demand on the environment. Product-as-a-service business models, for example, allow users to have full access to a product but pay only for the amount of product they use [20]. A variation of product-as-a-service is the shared-usage model. Zipcar, for example, provides customers with real-time access to vehicles when and where they need them. This substitutes for car ownership and has led traditional automakers to invest in the car-sharing market with offerings such as Turo from GM and DriveNow from BMW.

What is the true driver behind this amazing growth? In business and industry, the growth stems not solely from the automation of tasks but rather from the collection of data produced from the transformation of these newly automated tasks and operations. Mishler explains [21] that technology is implemented not randomly but for a specific business or industrial purpose. And the business enterprise justification for its investment in IoT applications is actually the new business intelligence (BI) gained by collecting and analyzing the data as well as the resulting information, knowledge and wisdom obtained from the generated processes and operations.

The capabilities of smart connected products are reshaping not only how the companies design, make and sell products but is transforming how companies market the products and services with consequent expansion of traditional business boundaries. This occurs since the basis of competition shifts from single isolated products, to product systems consisting of closely related products linked by a network of products and systems. Therefore, a set of distinct product systems integrated with sensed and stored data can be coordinated and optimized to create a smart building, a smart home, or a smart city, with the objective of maximizing a benefit and/or minimizing unwanted consequences of the use of the product.

Companies whose products and designs have the greatest impact on total system performance will be in the best position to drive this process and capture disproportionate value. In this new model, new features and functionality can be pushed to the customer on a regular basis. Product use and customer behavior can be tracked, and products can now be connected with other products, leading to new analytics and customer service experiences. In this new paradigm, individual firms must work with market partners and customers to create value chains organized to create value. To be successful, firms in the value chain must be able to collaborate at a new level, fully connected, to form the backbone of the IoT. The capability to offer closer customer interaction and a dynamic set of products and services are critical issues for companies to be successful in this new business model [22].

Therefore, in the context of IoT, business models describe how an enterprise plans to create value (i.e., generate revenues, offer innovative products or services) by generating, collecting and leveraging data, information, knowledge, intelligence, competencies, infrastructure and technology. But, in designing an IoT business model, business developers must still carefully analyze the enterprise's strengths, weaknesses, opportunities, and threats, in order to maximize profits while minimizing costs and potential risks.

Overall, as some authors point out [16],[23], it is not easy to identify, grasp and generalize how traditional business models will be affected, besides that they will be changed. There is just too many of them, with 55 extracted and analyzed by Gassmann et al. [24]. It is safe to say, however, that each industry, or even company, will definitely see their business model affected by IoT, so they would have to incorporate it into their business plans. Whether new business models will remain vertical or will cross industry boundaries remains to be seen.

Impact on Supply Chain

These smart, connected products offer enormous opportunities for new functionality, improved reliability, increased utilization rate, and capabilities that cross traditional product boundaries. The changing nature of products is also disrupting traditional supply chains, forcing companies to rethink and retool nearly everything they do internally and externally.

In the energy sector, ABB's smart grid technology [25] makes use of new design concepts and advanced materials in system components like transformers and circuit breakers to improve efficiency, safety and operational performance. The widespread use of power electronic devices will help maximize performance of existing assets and make the grid more resilient in the event of disruptions. It also enables utilities to analyze huge amounts of real-time data across a wide range of generating, transforming, and distribution equipment such as changes in the temperature of transformers and secondary substations. In consumer goods, Haiku ceiling fans invented SenseME technology [26], which sense and engage automatically when a person enters a room, regulate speed on the basis of temperature and humidity, and recognize individual user preferences and adjust accordingly.

Consider that in the IoT all kinds of objects from refrigerators and toasters to clocks and food containers will have a "smart" component with sensors which will make them aware of real-time conditions, and connectivity, which in turn will let them communicate those conditions instantly via the Internet.

This means a surge of data everywhere, which invariably make systems, and the supply chain, more complex to understand and manage. Consequently, the IoT will bring new demand patterns to the supply chain, forcing managers to search for new solutions to compete. The IoT will fundamentally change the way companies assess and plan activities, collaborate among partners, and produce and deliver goods and services. Using the advantages which the new technology brings, such as the extraordinary end-to-end visibility from every singular process and transaction, companies will have access to vast amount of information leading to a new kind of predictive insights for supply chains – one where adverse conditions, like a transportation delay, will do more than just trigger an exception alert. They will cause systems to assess priorities, weigh choices, and make course-correcting decisions in real time. Furthermore, these smart devices, producing data at several levels within the supply chain, from suppliers to customers, will bring new business insights for retailers, distributors and manufacturers, which must collaborate and share data at a new level to effectively harness the power of IoT, and therefore undergo a digital transformations to develop new business opportunities if companies want to survive in the new “disruptive” paradigm.

IoT is positively “disruptive and important” to supply chain strategy [27]. A recent survey by O’Marah [27] illustrates how this IoT is impacting strategies among leading supply chain executives (Table 1). Making the top three both years – and rising in importance sharply from 2014 to 2015 – Internet of Things is considered “disruptive and important” by nearly two thirds of respondents, while only 5% say it is irrelevant.

Table 1. Perception of the impact of IoT on supply chain (1000 respondents)[a]

Year	Disruptive & Important	Interesting but usefulness unclear	Irrelevant
2014	45%	42%	13%
2015	64%	31%	5%

a Source [27].

Managing supply chains in the IoT means more complexity since in this environment there is greater demand for speed and customization, which in turn places further pressure on supply chain members to make improvement in their operations to real-time market conditions, and deliver high levels of operational excellence. While supply chain management is already supported by various IT solutions, IoT can be of greater value by providing additional layer of support because of the capability to trigger critical processes in the supply chain when sensing changes in the product use and conditions, from material processing to end-user applications. Therefore, devices and equipment in the IoT leverage Internet connectivity to create a more preemptive supply chain in which problems are identified much quicker, described with precision nourished by sensor data, and possibly corrected without human intervention.

For example, new sophisticated RFID chips used in IoT allow the recording of manufacturing information, production date, expiration date, warranty period, after sales details allowing real-time and more efficient supply chain management. When after sales data feed into the manufacturing system, productive capacity can be adjusted, or a process modified to address quality and performance of the product, thereby providing means for exceptional gains in productivity. The speed and transparency of data can lead to increased cost saving with positive impact in the bottom line.

In logistics and transportation, the load carried by a logistic operator with smart objects, which can make information about transport available to the entire supply chain, and therefore making the chain more transparent, brings operational advantages. The smart items monitor the goods and proactively raise an alert if transport conditions, detected via GIS feed, are not appropriate anymore and plan a more efficient route. This potentially reduces product returns and late delivery, and lowers transport cost. The trick will be to make sense of that data. Leading companies will distinguish themselves by exploiting data, through analytics, to create systems that predict and prescribe actions in anticipation of approaching needs.

However, supply chain management in the IoT environment is not only about getting products faster, cheaper, and of better quality but also about getting managers the right information at the right time, so that they can better make informed supply chain decisions. This new paradigm means greater end-to-end visibility and predictive power. For the first time in history, complex global supply chains have the capability to connect with their products and processes to achieve new levels of supply chain visibility. According to Ellis et al. [28], from a broad range of industries, manufacturing, construction engineering, and transportation have a high or very high level of deployed or planned to deploy IoT strategies making them leaders in the new paradigm, which is consistent with the pattern in previous technology wave such as bar coding, RFID, and wireless connectivity among others.

Challenges and Business Risks

What are the business risks of introducing IoT? Surely, as billions of devices gain the ability to collect and share these vast amounts of data, spanning from health monitors and fitness trackers reporting health statistics to washing machines and freezers alerting users, there is little control and safeguards over the collection, retention, distribution and usage of the data. These massive collections of data create significant security risks in both business and industry. Furthermore, there are unanticipated security risks which will expose users to outside threats. If hacked, information gathered from various objects could reveal enough personal and corporate information which will seriously jeopardize and exposure the individual's and business' practices and secrets. More importantly, Distributed Demand of Services (DDoS) attacks will continue to increase, as hackers are able to penetrate more networks. Due to these concerns, there is a growing need for regulatory action, as well as technical advances, to protect the rights of the user to privacy and security. All these are key factors in the IoT adoption considerations in both business and industry.

Indeed, security concerns and need for regulations are the most immediate factors to address, so to summarize:

- security, since we not necessarily know very well how to protect the entities against an unauthorized access, that is, ensure confidentiality and integrity of data, at this scale of operations and that many factors contributing to the data processing,
- regulatory and legal issues, which are hard to predict but generally mean compatibility with existing laws, although very likely new laws would have to be considered.

With the technology of that scale and, at the same time, that new, there are a number of other challenges, which it brings, among them the following [3]:

- privacy issues, that is, protection of the rights of an individual in a view of potential exposure of personal information,
- interoperability and standards, which means ensuring that the participating entities speak the same language, that is, understand the same communication protocols to provide the user with „plug-and-play" capability,
- impact on economy, especially on emerging economies and developing countries, since the technology provides enormous opportunities that are hard to quantify.

Addressing all these challenges and, especially, attempting to solve related problems, is an overwhelming task and remains outside the scope of this paper.

Conclusion

Where does it all go? Regarding the first question asked in the Introduction: "How is the Internet-of-Things changing business and industry?" – it is clear that creating value from information can have potentially profound implications for competitive advantage and as a driver of innovation. The IoT paradigm is changing the rules of competition and the industry structure itself, generating new business models and news ways to connect to members of the supply chain, and creating lasting value for consumers.

Regarding the second question: "What will be the effect of IoT technologies on business operations, productivity, effectiveness and efficiency?" – some companies, such as Amazon, Azure, John Deere and ACGO, are intentionally seeking to broaden and redefine their industries [29]. Other companies may find themselves threatened by this new business model, which creates new competitors, new bases for competition, and the need for entirely new and broader capabilities. Companies that fail to adapt may find their traditional products becoming commoditized or may themselves be consigned to the role of supplier, with system integrators in control.

Looking at both above-mentioned questions jointly, one way of viewing the future of the IoT is to see it from a much broader perspective, such as the integration of vertical markets. Currently, each application domain or industry (vertical market) clearly develops its own techniques and ways of using the IoT. What the future would bring is the cross-fertilization of ideas and practices to expand over different application domains (industries). A few research propositions already exist that look at it, for example [30], calling it Inter-IoT.

Finally, it is much harder to answer the third question posed in the Introduction, about the impact of IoT: "Can the inherent risks, which it brings, such as security, be mitigated, in a way that business and industry would openly embrace the new opportunities?" As mentioned in the previous section, this issue requires a much deeper insight into a variety of related factors, at the technical level, so that a separate, more focused, study is needed to address it.

There are quite a few other topics not covered in this paper. One of them is software and its significance in the IoT environment. One cannot overemphasize the role of software, at all stages of the IoT architecture model. Be it the programming of device things, communication software or middleware, the cloud itself, which is pure software, analytics and security, all of it require sophisticated software techniques and algorithms, the descriptions of which is out of scope of this paper.

One big issue remains unsolved, yet, how exactly the robots will be interacting with the physical world, in the context of the IoT. This is especially a critical question in a view of the growing interest of using drones for business purposes. Although telerobotics is not new and remote robotic operations have a vast literature, and there are attempts to address this problem in IoT calling it Internet of Robotic Things (IoRT) [31]-[32], it is not perfectly clear how the robotics technology will blend with the rest the IoT and provide benefits across the board, not only to particular industries, such as manufacturing.

Although the Internet of Robotics Things does not yet exist in a mature state, the field of manufacturing automation is well established. It concerns the intelligent control of flexible manufacturing systems where the manufacturing plant produces small quantities of different types of products and is mostly or totally automated using robotic manipulators and other types of automated machines. These systems always run in a transient state and their control and optimization presents a difficult problem requiring real-time intelligence. As these systems become larger and more distributed, their intelligence, consisting of Monte Carlo type discrete-event simulations, needs to become distributed to scale to the growing size of the control domain of the system [33]. The idea of the IoRT is to take advantage of the IoT to perform distributed intelligence that can be used in the control of such large scale distributed automated systems.

Last but not least, since the paper concentrated on discussing technical issues vs. business issues, there was no room for addressing education. But one should make no mistake, for any new technology to persist, whether disruptive or not, it is essential to educate cohorts of engineers and businessmen to bring this technology to life. As important as it might be, this is a topic for a different paper, however, and has been addressed in a recently published work [34], although only from the software engineering perspective.

Similarly, as this paper's focus was on the industrial/business aspects of IoT, there is no mention of the use of IoT in the government and public sector. Again, this important topic is a venture in itself and requires a separate analysis. There are, however, interesting reports already published touching on the subject [35]-[36].

Overall, one has to also remember that sensor data, so widely advertised as the major component of the IoT are only good enough if one can make use of them. Why do we collect data after all? Primarily to determine the course of action, that is, to take decisions. And this is the ultimate objective, which will guide the evolution of the IoT both from the technical and from the business

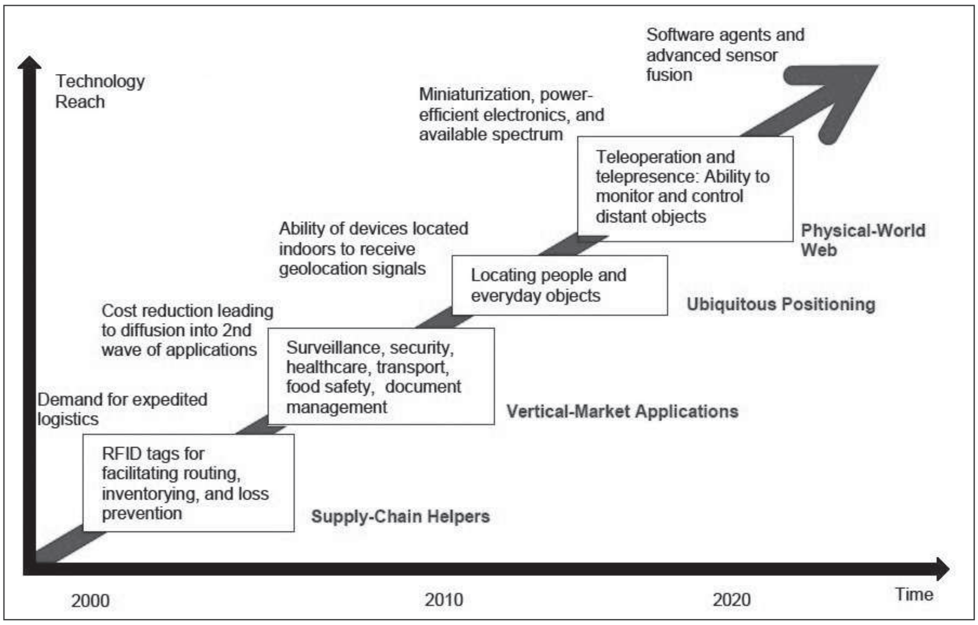

Fig. 5. Technology Roadmap for the Internet of Things [37]

perspective. If one wants to realize where the entire IoT is leading us, they may take a look at Figure 5, adopted from the report produced as a result of a conference on Disruptive Civil Technologies in 2008 [37].

References

1. IEEE Standards Association (2016) P2413 – *Standard for an Architectural Framework for the Internet of Things (IoT).* New York: Institute of Electrical and Electronics Engineers.
2. IEEE Standards Association (2014) *IEEE Standards Association (IEEE-SA) Internet of Things (IoT) Ecosystem Study.* New York: Institute of Electrical and Electronics Engineers.
3. Rose K., Eldridge S., Chapin L. (2015) *The Internet of Things:* An Overview. Geneva, Switzerland: Internet Society.
4. Voas J. (2016) *Networks of Things. Gaithersburg*, MD: National Institute of Standards and Technology.
5. LaPlante A. (2016) *Analyzing Data in the Internet of Things*. Sebastopol, Calif.: O'Reilly.
6. Kraemer B. (2016) P2413 – *Standard for an Architectural Framework for the Internet of Things.* New York: Institute of Electrical and Electronics Engineers.
7. Doukas C. (2012) *Building Internet of Things with Arduino*. Athens, Greece: self-published.
8. Norris D. (2015) *Internet of Things:* Do-It-Yourself at Home Projects for Arduino, Raspberry Pi and BeagleBone Black. New York: McGraw-Hill.
9. Weaver J., Chin S. (2015) *Raspberry Pi with Java*: Programming the Internet of Things. New York: McGraw-Hill.
10. Laney D. (2001) 3D *Data Management:* Controlling Data Volume, Velocity, and Variety. Stamford, Conn.: META Group, Inc.
11. Stonebraker M. (2010) *SQL Databases vs. NoSQL Databases*. "Communications of the ACM", 53 (4): 10-11.
12. Mell P., Grance T. (2011) *The NIST Definition of Cloud Computing*, Special Publication 800-145, Gaithersburg, MD: National Institute of Standards and Technology.
13. Amazon Web Services (2016) URL: https://aws.amazon.com/
14. Microsoft Azure (2016) URL: https://azure.microsoft.com/en-us/
15. HIT Consultant (2015) AWS, Philips Strengthens Partnership to Unleash Digital Health IoT. URL: http://hitconsultant.net/2015/10/09/aws-philips-strengthens-digital-health-iot/
16. Amiot E. et al. (2015) *The Internet of Things: Disrupting Traditional Business Models.* New York: Oliver Wyman Group.
17. Barkai J. (2016) *The Outcome Economy: How the Industrial Internet of Things Is Transforming Every Business*. CreateSpace.
18. Norton D. (2016) *Digital Context 2.0: Seven Lessons in Business Strategy, Consumer Behavior, and the Internet of Things.* Gifted Press.
19. Wright K. (2015) *What Key Disruptive Effects Have and Will the Internet of Things or Physical Computing Have on Business and Our Daily Lives?* GRIN Verlag GmbH.

20. Porter M.E., Heppelmann J.E. (2014) *How smart, connected products are transforming competition*. "Harvard Business Review", 92 (11): 64-88.
21. Mishler C. (2015) *The Future of the Internet of Things*, "Strategic Finance", 96 (11): 62-63.
22. Kindström D. (2010) *Towards a service-based business model – Key aspects for future competitive advantage*. "European Management Journal", 28 (6): 479-490.
23. Fleisch E., Weinberger M., Wortmann F. (2014) *Business Models and the Internet of Things*. St. Gallen, Switzerland: Bosch Internet of Things & Services Lab.
24. Gassmann O., Frankenberger K., Csik M. (2015) *The Business Model Navigator: 55 Models That Will Revolutionise Your Business*. Indianapolis, Ind.: FT Press.
25. ABB Ltd (2016) *Smart Grids – Highlights*. Zurich, Switzerland. URL: http://new.abb.com/smartgrids
26. Hayku (2016) *SenseME Technology: The Brains Behind Haiku Home*. Lexington, Kentucky, USA. URL: http:www.haikuhome.com/senseme
27. O'Marah K. (2016) *Beyond Supply Chain*. SCM World, May 13.
28. Ellis S., Morris H.D., Santagate J. (2015) *IoT-enabled analytic applications revolutionize supply chain planning and execution*. IDC White Paper #259697. Framingham, Mass.: International Data Corporation.
29. Iansiti M., Lakhani K.R. (2014) *Digital Ubiquity: How Connections, Sensors, and Data Are Revolutionizing Business (Digest Summary)*. "Harvard Business Review", 92 (11): 91-99.
30. Ganzha M., Paprzycki M., et al. (2016) *Semantic Technologies for the IoT – An Inter-IoT Perspective*. Proc. IoTDI-2016, First IEEE Intern. Conf. on Internet-of-Things Design and Implementation, Berlin, April 4-8, 2016, pp. 271-276.
31. ABI Research (2014) *The Internet of Robotic Things*. Technology Analysis Report AN-1818. New York.
32. Shein E. (2016) *The Beginning of the Internet of Robot Things*, ACM News, August 11.
33. Gonzalez F.G. (2013) *Real-Time Simulation and Control of Large Scale Distributed Discrete Event Systems*, Proc. CSER'13, 2013 Conference on Systems Engineering Research, Atlanta, GA, March 19-22, 2013, pp. 177-186.
34. Gonzalez F., Guo D., Nowicki A., Zalewski J. (2017*) Senior Lab Projects for Teaching the Internet-of-Things in a Software Engineering Program*. Proc. eTEE'201, 4th Intern. Conference on e-Technologies in Engineering Education, Gdańsk, Poland, April 27-28, 2017.
35. Castro D., New J., McQuinn A. (2016) *How is the Federal Government Using the Internet of Things?* Washington, DC: Center for Data Innovation.
36. Andrews C. et al. (2016) *The Internet of Things: What the IoT Means for the Public Sector*. Washington, DC: GovLoop.
37. SRI Consulting Business Intelligence (2008) *Disruptive Civil Technologies. Six Technologies with Potential Impacts on US Interests out to 2025*. Appendix F. The Internet of Things (Background). Washington, DC: National Intelligence Council.