PERSPECTIVES OF DEVELOPING INDUSTRIAL INTERNET

Radu DOBRESCU[1]

Abstract. *The adoption of IoT by industries has led to the next industrial revolution: Industry 4.0. The rise of the Industrial IoT (IIoT) promises to enhance factory management, process optimization, worker safety, and more. However, the rollout of the IIoT is not without significant issues. This paper aims to illustrate the way that IIot evolves, under the wider umbrella of the Internet of Production, in a configuration of eco-systems based on Internet support and web services.*

Keywords: Internet, Industry 4.0, Industrial Internet of Things, Production Internet, eco-systems

1. Introduction

The growth of the Internet of Things (IoT) is drastically making impact on home and industry. While the IoT affects among others transportation, healthcare, or smart homes, the Industrial Internet of Things (IIoT) refers in particular to industrial environments. IIoT is a new industrial ecosystem that combines intelligent and autonomous machines, advanced predictive analytics, and machine-human collaboration to improve productivity, efficiency and reliability. It is bringing about a world where smart, connected embedded systems and products operate as part of larger systems.

IIoT is often used in the context of Industry 4.0, the promoter of a new industrial revolution with a focus on automation, innovation, data, cyber-physical systems, processes, and people. With Industry 4.0, the fourth industrial revolution is set on merging automation and information domains into the industrial Internet of things, services, and people. The communication infrastructure of Industry 4.0 allows devices to be accessible in barrier-free manner in the industrial Internet of things, without sacrificing the integrity of safety and security.

The term “industrial Internet” was coined by Industrial giant GE to describe industrial transformation in the connected context of machines, cyber-physical systems, advanced analytics, AI, people, cloud, and so on. GE and the Industrial Internet Consortium (IIC) decided that IIoT was a synonym for the Industrial Internet [1]. IIoT is poised to bring unprecedented opportunities to business and society. Organizations like IIC and IEEE are working hard to define and develop the IIoT.

The rise of IIoT promises to enhance factory management, process optimization, worker safety, and more. However, the rollout of the IIoT is not without

[1] Prof., Control Systems and Industrial Informatics Dept., Univ. “Politehnica” Bucharest, Romania

significant issues, and many of these act as major barriers that prevent fully achieving the vision of Industry 4.0. One major area of concern is the security and privacy of the massive datasets that are captured and stored, which may leak information about intellectual property, trade secrets, and other competitive knowledge. To overcome these difficulties is suitable to identify common input-output (I/O) design patterns that exist in applications of the IIoT. These design patterns enable constructing an abstract model representation of data flow semantics used by such applications, and therefore a way to a more generalized and Big Data adequate Web-based infrastructure. This infrastructure which covers a larger domain than IIoT is the Production Internet (PI).

Production Internet goes beyond the peer-to-peer based Web-services for economic exchange. The breaking innovation is by support of structured workflows of products/services, and also by automated matching of demands and resources. The most vital for PI success are Web services and semantic technologies [2]. The other important are: multi-agent systems, smart technologies and CPS, cloud computing, and Service Oriented Architectures (SOA). More of that, as a key Web-based eco-system, PI finds a central place in the most sophisticated family of the Seven Internets [3].

The focus of this paper is on the functional development of Industrial Internet, its integration in Production Internet, and the perspective to be assimilated as a web-based eco-system.

2. Related works

Almost all the papers on IIoT refer to the multiple aspects that all stake holders will need to consider both in IT world and Industry 4.0. The most recent explore the role that IoT and related technologies such as cyber-physical systems (CPS) play in the implementation of Industry 4.0. These aspects are discussed in various works, which define: (i) smooth integration of the newly developed IoT sensors (things) into existing industries [4]; (ii) transparent secure communication channel and software layer to link manufacturing data with cloud based SW platforms [5]; (iii) developing a standard IIoT and industrial CPS architectures [6]; open standards vital to guarantee interoperability of hundreds of millions of Internet-connected things [7]; (v) development of energy efficient IoT sensors and devices[8]; vi) the sustainability impact and challenges of IIoT, big data analytics, and CPS [9]; vii) using IIoT in business applications [10].

We recommend also to consult the systematic literature review on Industry 4.0 made by Liao et al. [11] which found about 250 papers (published before July 2016), which present not only the developing trends of IoT in the industry, but also the conection of IIoT with broader, but also abstrac concepts: the Internet of People (IoP) and the Internet of Everything (IoE).

3. Basic Principles of the IIoT

Along the years, a flurry of research work has been aimed at applying IoT concepts in industrial control system (ICS) environments, to the point that industrial IoT (IIoT) is nowadays considered one of the pillars of Industry 4.0. Bringing IoT concepts into an industrial environment further exacerbates security concerns, because in the industrial setting, security is very often tied to safety. For instance, it is conceivable that a security breach in a factory could easily damage plant machines and lead to physical injury to the human operational or maintenance personnel. Figure 1 shows the mapping of the traditional pyramid of automation with an architectural framework of the IIoT using three primary layers. The integration of the pyramid layers by using the IoT layers is the cornerstone of Industry 4.0.

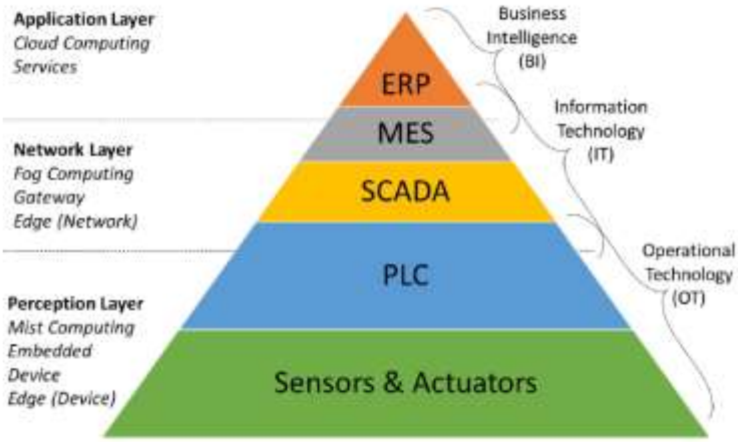

Fig. 1. Hierarchical Layers of IIoT and Relationship to Pyramid of Automation.

Three primary layers are representative of any IoT architecture: perception, network, and application. Another common naming scheme for these layers is the embedded, gateway, and cloud, respectively. Industry 4.0 results from the combination of IoT layers and elements with non-integrative manufacturing separated into the pyramid layers starting with the first operational technology layer of sensors and actuators, which are the interface to the physical assets of the shop floor, and moving up through the programmable logic controller (PLC) layer into the information technology layers: the supervisory control and data acquisition (SCADA), manufacturing execution system (MES), and finally the enterprise resource planning (ERP) in which business decisions are made.

Perception (Embedded, Edge) Layer: The perception layer is closest to the "Things" of the IoT and is often described in terms of sensor capabilities. Any sensor input, for example, RFID tags or barcodes, falls into this layer. In many IoT systems, this layer also includes actuators that enable the ability to influence the physical world.

The combination of the sensors, actuators, and their associated computational hardware/software is often referred to as an edge device or an IoT node. The responsibilities of the edge device in the perception layer are to collect sensor data from the physical environment, process the data locally - possibly in real-time - and then communicate data with other edge devices or through the network. The communication between nodes in this layer, and occasionally between edge devices and the network layer, uses both wireless and wired connections.

Network (Gateway) Layer: The network or gateway layer facilitates the communication of information provided by the perception layer using wireless, cellular, wired, and Internet network technology. The IoT nodes in this layer are referred to as gateways or hubs. The network layer employs cutting-edge communications technologies to transmit information between the edge and the cloud. Typical technologies at this layer include WiFi, Ethernet, and Cellular. As information is transmitted through this layer, the gateways may filter and aggregate the data in some IoT systems.

Application (Cloud) Layer: The application layer is where the IoT intelligence appears. The practical possibilities of IoT come to the fore at this level by leveraging the vast storage and computational capabilities of cloud data centers to employ big data analytics on the distributed sensor data produced in the perception layer and aggregated through the network to this layer. The application layer for specific IoT products may consist of one or more public or private clouds. Private clouds have the advantage for their operators of maintaining data control and ownership, which is important for sensitive information such as intellectual property or personally identifiable information. Their disadvantage is the cost to establish, maintain, and manage them. The emergence of an IIoT is revolutionizing nearly all aspects of modern industry.

Usually four primary categorical areas of IIoT applications are considered: infrastructure, supply chain, process control, and maintenance. No one size fits all architecture easily adapts to the heterogeneous devices and communication protocols used in the IIoT. Therefore, in order to understand complex system designs, a systematic approach of categorizing and controlling heterogeneity can be adopted by system designers, engineers, and operational analysts. Design patterns offer one such approach by identifying reusable components within a system and providing solutions to recurring problems based on those components. As a design aid, theses patterns can be used as a guide by non-domain experts to properly analyze a system by recognizing the patterns.

One can to identify design patterns in the IIoT by the modality they respond to the requirements to be: (a) abstract to specific computing devices and communication protocols; (b) composable to allow multiple patterns to be easily combined;

(c) recognizable from typical system components found in the industrial setting; (d) data-centric to focus patterns on dataflow semantics as enabling better understanding of resource provisioning and information security requirements.

In the past couple of years, the Industrial Internet Consortium devoted a significant effort to defining the Industrial Internet Reference Architecture (IIRA) [12]. IIRA is an open architecture for IIoT system that aims at having broad industrial relevance and applicability while leaving system architects ample design choices.

It revolves around the key concept of viewpoint, an entity that frames the description and analysis of a specific set of concerns. In turn, concerns are aspects or characteristics of a system of interest to stakeholders, that is, people or organizations in charge of the system.

While the IIoT undoubtedly offers many advantages, it is not without problems. One of the biggest challenges associated with the increased popularity of the IIoT is that the vast amount of data produced by manufacturing systems, which will be more and more difficult to collect, curate, and analyze.

Additional problems are also anticipated in terms of governance, systems management, security, and privacy.

We believe that design patterns can provide a framework to use when trying to solve these problems. This framework broader than IIoT itself is the Production Internet (PI).

4. Functionalities of Production Internet

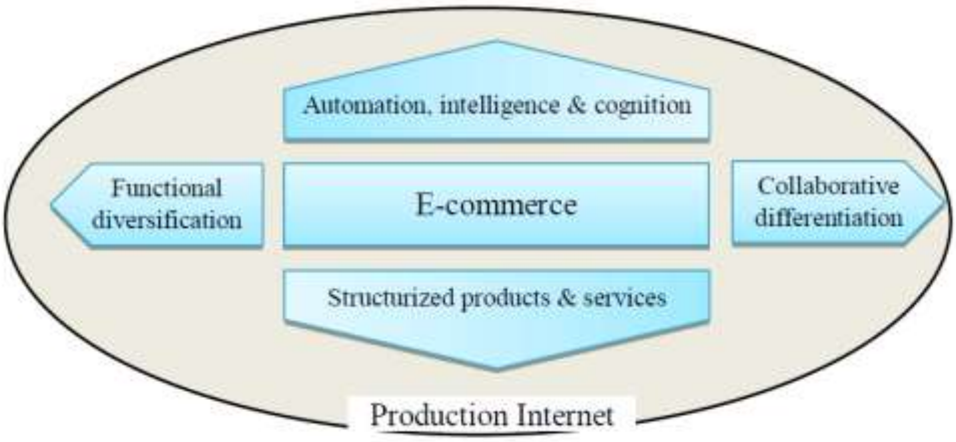

Fig. 2. Evolution towards the Production Internet.

The PI development is close related with the concept of eco-system. The eco-systemic solution of Production Internet should significantly limit the shortcomings of existing economical institutions, especially by: improved operational performance, increased sharing and utilization of resources, improved transaction costs economics, improved economic performance of economic exchange.The findings from the foresight research suggest a particular evolutionary pattern for development of the PI, which is exhibited below in Fig. 2.

It is suggested that the E-commerce ecosystems should be viewed as the conceptual basis for initial developments of PI, which have to start from a breaking innovation – consideration of products and manufacturing services as structured items.

This grounding development shall be followed in a twofold way by functional diversification, i.e. by adding consecutive functions, and collaborative diversification, i.e. by adding new actors of cooperation, as well as consecutive forms of economic exchange. The crowning of Production Internet will be throughout a progressive enrichment by automation, artificial intelligence, including the autonomous cognition. Possibly bio- or eco-mimetic emergent intelligence to support the homeostasis of the production ecosystems can be innovated at the end.

The foresight research enabled identification of functionalities to be offered by the first generation solutions of the PI.

Considering the welcome impact of this innovation, and taking into account the probable roadmap towards first developments, the following functionalities have been selected as the primary targets: **1.** Offering of structured products (from stock or manufactured) and manufacturing services; **2.** Offering of resources (processing, warehousing, forwarding); **3.** Credibility assessment; **4.** Bidding, auctioning, discounting; **5.** Qualitative, quantitative and spatio-temporal matching of demands and provisions; **6.** Operational coordination of material, work and information flows; **7.** Product and process data management; **8.** Demand and orders processing and tracking; **9.** Claims and returns management; **10.** Payments management.

The development is supported by two key ICT technologies: multi-agent systems and ontology engineering. The multi-agent environment provides capacity for mimicking Web services and Web-based interactions. Additionally it provides a setting for the Service-Oriented Architectures and cloud-based infrastructures.

It was also considered as the initial technology to automate coordination activities. Using the prognostic approach, a reference functional architecture which is organized into four layers was elaborated [Fig. 3].

All of them presume multi-agent/robot setting to manage services. All robots are equipped with own operational ontologies.

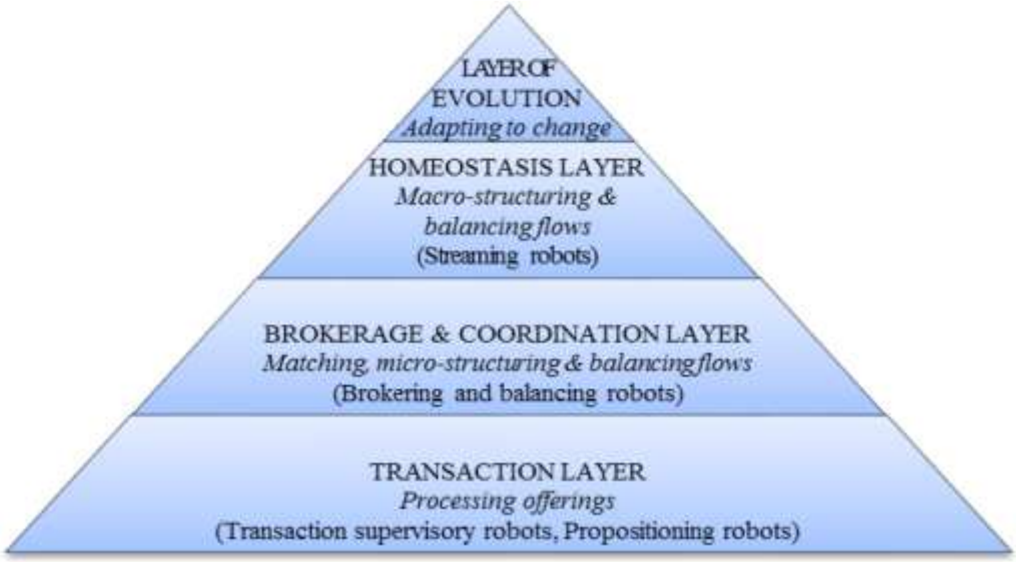

Fig. 3. Prototype setup of Production Internet - generic layered structure.

The brokerage & coordination layer includes robots aligning demands and offerings, by spatio-temporal matching of products, resources, services and demands. The transformational approach is applied to explode and aggregate demands, and then services. The bottom layer interfaces processes, resources and users. The propositioning robots handle offerings, while transaction supervisory robots manage load of resources, fulfillment of internal orders, receiving, and forwarding. As yet, top two layers are still in construction.

The homeostasis layer takes aggregate view of operations and focuses on overall balance of loads and flows. It concerns blockings and jams caused by temporal overloads of capacities and reduced supplies. Alternative streaming of flows can be advised to the balancing robots in lower layer. The role of this layer is similar to aggregate planning and follows the idea of adaptive control.

The layer of evolution considers self-adoption of ecosystem including autonomous cognition. New behavioral patterns can be self-learned with regard to the observed changes, e.g. in terms of variability, mix of services. The change can be implemented by advising new rules to robots operating in lower layers.

The prototype development employs a limited scope of functionalities and does not pay attention to the scalability. This kind of approach can be justified by the focus of the initial implementation on functionalities, and with this regard - discovery of particular issues that can be faced in the future along the further extension of the Production Internet.

Extension that, as for all of Web-based eco-systemic developments, is coined to the Seven Internets paradigm.

5. Seven Internets Paradigm

The major engines of technology-based developments along the two recent decades were the Internet, and the Web-based services. The existing Internet of data is expected to evolve towards the Semantic Web. The Semantic Web would provide a common framework that allows data to be shared and reused across applications, organizations, and community boundaries. The most distinctive areas of Semantic Web based developments are referred as the Seven Internets [3] which are: Social Internet, Commercial Internet, Production Internet, Physical (Logistics) Internet, Financial Internet, Internet of Things, and Energy Internet (Smart Grids), as presented in Fig. 4.

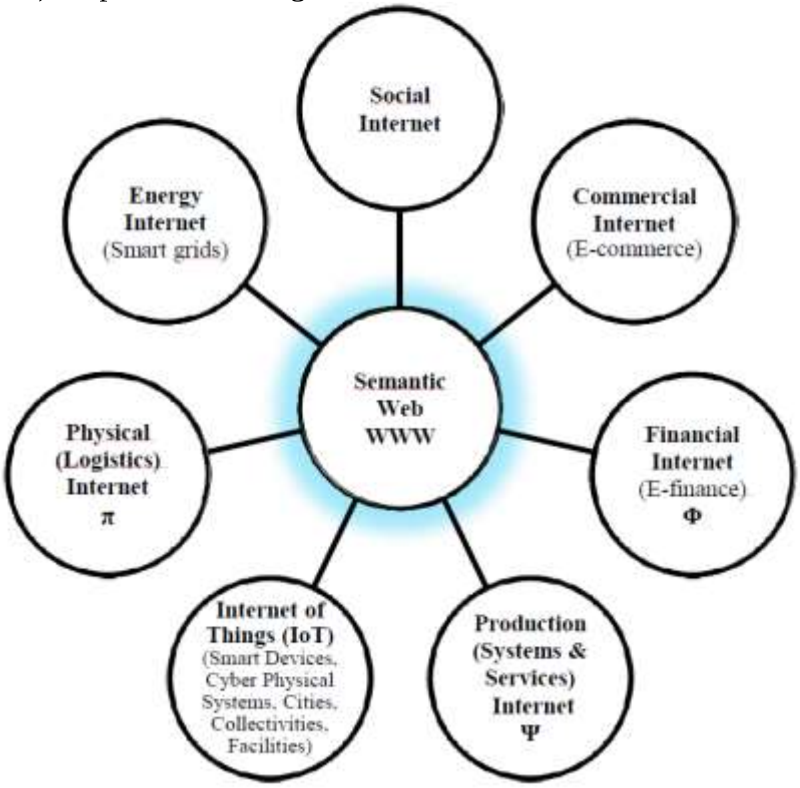

Fig. 4. Semantic web-driven Seven Internets.

The existing Internet of data supplemented with the new capacities of Semantic Web, would provide a public infrastructure for information exchange to the other Internets. Some of them are pretty advanced and undergo intensive development, like especially the Social Internet, the Financial Internet (**Φ**) and the Commercial Internet. Other Internets are still more ideations than reality. Nevertheless, significant efforts towards their development are undertaken and considerable support is offered by the funding bodies, as all of them were put to the top of research agendas.

Production Internet, or in a more complete definition Production Systems & Services Internet (**Ψ**) has been originally defined by Strzelczak [13]. Due to the positioning of **Ψ** in relation with other Internets, it is expected to match and align the demand coming out of the Commercial Internet, with the available provisions offered by the networked production systems services (see Fig. 5).

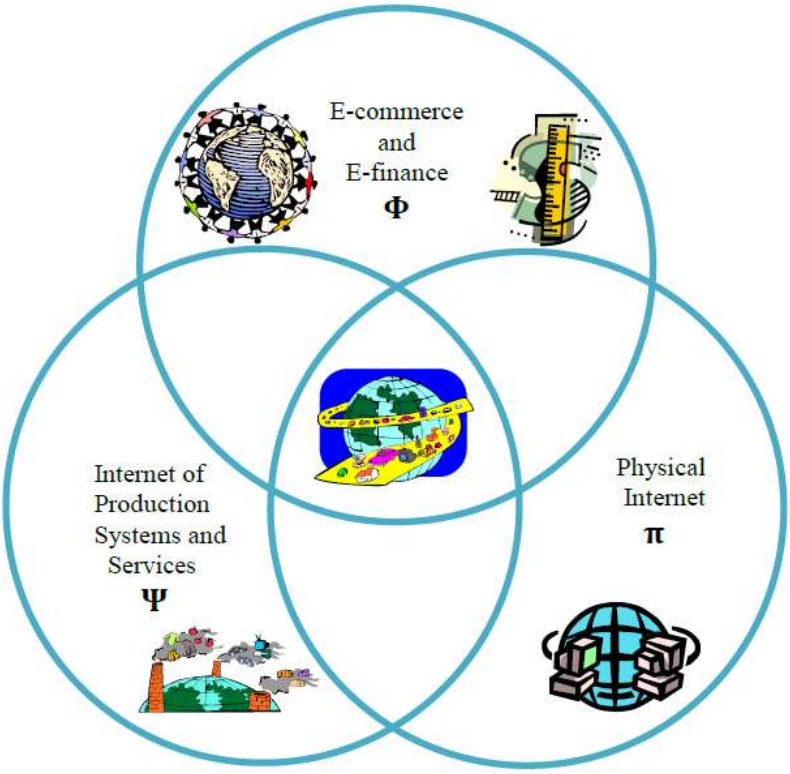

Fig. 5. Positioning of Production Internet (after [13]).

The bulking and encapsulation of the demand, and of the resource provisions, would be integrated by the means built upon Semantic Web, while the resources of **π** and **Φ** would support in an integrated manner the operations of **Ψ** towards the customers.

The development of PI has to face a particular difficulty. While the other Internets operate mostly on a peer-to-peer basis, herein the links between demand and supply flows are subjected to various couplings (see Fig.6), which normally exhibit the nature of spatio-temporal mereotopological relationships.

Therefore, harmonizing the two streams requires an additional coordination support, which could be provided by some kinds of Web services operating by various modes, ranging from hierarchical to heterarchical.

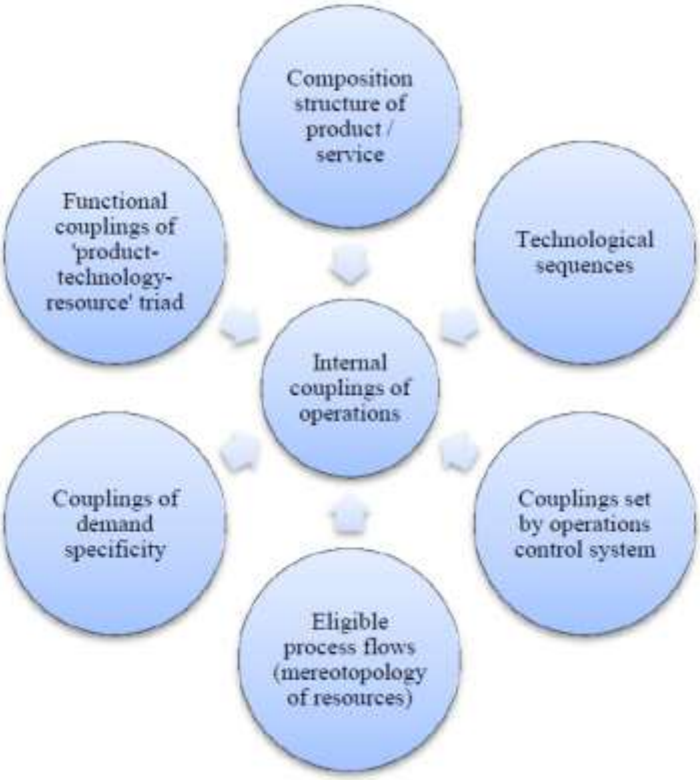

Fig. 6. Internal couplings of operations.

Enabling smooth, fast, cheap, reliable alignment of distributed demand and manufacturing resources, by merging its capacities with **π**, the Production Internet is expected to reduce or eliminate many shortcomings of the existing economies, namely:

1. The economic order quantities of logistics flows and manufacturing batches can be exploited in parallel.

2. The matching of demand and manufacturing provisions can be operated in a more flexible way.

3. Spatial matching of demands and provisions can be exploited by the means of **π**, building the synergy of both Internets this way.

4. Operations can be streamed and streamlined, while manufacturing activities can be servitized.

5. The transaction costs economy can be tamed, giving more space to open market-like economic institutions.

6. The economic forces that push towards geographically concentrated economy, can be much reduced. Hence, the local communities can be hopefully revitalized.

The **Ψ** is expected to rely on the Internet of Things (IoT), which aims at enabling ubiquitous connection of physical devices equipped with the smart connective technology (RFID, sensors, cameras, GPS, Internet, etc.), capable of generating and collecting data by themselves, capacitated with the distributed self-control through the networked networks of IoT. The Cyber-Physical Systems are commonly understood as complexities of embedded systems integrated into various devices and facilities that are eventually endowed with the Human-Machine Interfaces (HMI).

6. Conclusions

We can resume our presentation in a short sentence: "The new economy will be surely intelligent".

The meaning of Intelligent Economy is exact. It is featured with three distinctive characteristics:

1. The networked resources: the economic assets are interlinked and co-operated by the means of Semantic Web in a run-time mode, therefore the advantages of real-time coordination can be exploited to improve the overall efficiency and effectiveness;

2. The networked processes: the transformation and provision of goods is driven by open and knowledge-aided solutions, which facilitate streaming and streamlining of the material, work and knowledge flows;

3. The intelligently harmonized demands: the spatio-temporal allocation and alignment of demand is controlled by Web services that are equipped with intelligent capabilities, to exploit various economies of scale and advantages of the subscribed demanding, and putting away the existing model of time stressed economy.

Altogether the Intelligent Economy is built and based upon the infrastructure of Seven Internets and will bring the benefit of sustainable development, by improving the harmony of society, economy, and nature.

R E F E R E N C E S

[1] M. N. O. Sadiku, Y. Wang, S. Cui, S. M. Musa, Industrial Internet of Things, *International Journal of Engineering Research and Advanced Technology*, vol. 3, no.11, **2017**, pp. 1-5.

[2] S. Strzelczak, Production Internet - Functional Perspective, *Proc. of the IFIP International Conference on Advances in Production Management Systems*, **2017**, pp. 48-56.

[3] S. Strzelczak, Towards intelligent and sustainable economy - from incas, through eScop, to the Seven Internets, *Proceedings of the International Conference on Technology, Intelligence and Future*, **2015**, pp. 324–336.

[4] L.M. Zawra, H.A. Mansour, A.T. Eldin, N.W. Messiha, Utilizing the Internet of Things (IoT) Technologies in the Implementation of Industry 4.0. In: Hassanien A., Shaalan K., Gaber T., Tolba M. (eds) *Proceedings of the International Conference on Advanced Intelligent Systems and Informatics*- AISI 2017, vol 639, Springer, **2018**.

[5] S. K. Rao and R. Prasad, Impact of 5G Technologies on Industry 4.0, *Wireless Personal Communications*, 100(1), **2018**, pp. 145–159.

[6] P. Leitão, A.W. Colombo, S. Karnouskos, Industrial automation based on cyber-physical systems technologies: prototype implementations and challenges, *Computers in Industry*, 81, **2016**, pp. 11–25.

[7] M. Chung and J. Kim, The Internet Information and Technology Research Directions based on the Fourth Industrial Revolution, *KSII Transactions on Internet and Information Systems*, vol. 10, no. 3, pp. 1311-1320, 2016. DOI: 10.3837/tiis.**2016**.03.020.

[8] M.T. Okano, IOT and Industry 4.0: The Industrial New Revolution, *Int. Conf. on Management and Information Systems*, **2017**, pp. 75-82

[9] S. Bonilla, H. Silva, M. Terra da Silva, R. F. Gonçalves, J. Sacomano, Industry 4.0 and Sustainability Implications: A Scenario-Based Analysis of the Impacts and Challenges. *Sustainability*, 10(10), 3740, **2018**.

[10] J.M. Müller, O. Buliga, O., K.-I. Voigt, Fortune favors the prepared: How SMEs approach business model innovations in Industry 4.0. *Technol. Forecast. Soc*., 132, **2018**, pp. 2–17.

[11] Y. Liao, F. Deschamps, E. de Freitas Rocha Loures, L.F.P. Ramos, Past, present and future of Industry 4.0—A systematic literature review and research agenda proposal. *Int. J. Prod. Res*., 55, **2017**, pp. 3609–3629.

[12] The Industrial Internet of Things Volume G1: Reference Architecture, *Industrial Internet Consortium*, **2017**, IIC:PUB:G1:V1.80:20170131.

[13] S. Strzelczak, Towards the **Ψ** – Production Services Internet. IOSP Research Report, Warsaw University of Technology, **2014**.