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INDUSTRIAL INTERNET AND ITS ROLE IN PROCESS AUTOMATION

Master's thesis for the degree of Master of Science in Technology submitted for inspection, Espoo, 18 March, 2016.

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Abstract

Modern process automation undergoes a major shift in the way it addresses conventional challenges. Moreover, it is adapting to the newly arising challenges due to changing business scenarios. Nowadays, the areas of the automation that recently were rather separate start to merge and the border between them is fading.

This situation only adds struggle to the already highly competitive production industry. In order to be successful, companies should adopt new approaches to the way their processes are automated, controlled, and managed. One of these approaches is the so-called Industrial Internet. It is the next step after the traditional paradigm of the process automation pyramid that leads to the new vision of interconnected processes, services, machines and people.

However, general company does not usually eager to implement the new technology to its business. One of the reasons for this is that it does not see the advantages that the Industrial Internet brings. This is due to the lack of sufficient number of successful implementation examples in various industrial areas and of clear business scenarios for the use of the Industrial Internet.

Aim of the presented thesis is to create a convincing Industrial Internet application scenario. For the implementation, a mineral concentration plant was chosen as one of the industrial premises that possesses the shortage of the Industrial Internet examples.

Literature review section describes the process automation state of art. It lists and reviews the research and development initiatives related to the Industrial Internet. Moreover, the Industrial Internet fundamentals are given. Finally, it describes the Industrial Internet applications and the case studies.

In the practical part, at first, the description of the mineral concentration plant is given. Then, the next section describes the Industrial Internet application scenario. In the following section technical guidelines for the system implementation are given. Also, in the concluding part of the thesis the future direction of research work are discussed.

Keywords Industrial Internet, IoT, concentration, scenario

Preface

This master's thesis has been written in the Research Group of Process Control and Automation, at Aalto University School of Chemical Technology during the period 7 April 2015 – 17 March 2016. This work is a part of the STOICISM project. STOICISM (The Sustainable Technologies for Calcined Industrial Minerals) is a major innovative research project launched in the beginning of the year 2013 under the Framework Programme 7 for the "New environmentally friendly approaches to mineral processing".

First of all, I would like to express my gratitude to my professor Sirkka-Liisa Jämsä-Jounela for such a great opportunity to work on my thesis in the Research Group. I would like to thank her for the guidance and salvational feedback.

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Last but not least, I would like to express the gratitude and love to my family and friends for their support, encouragement and faith in me during happy and sorrow? Moments. And I am so sorry, that my grandmother cannot witness the result of my work. I've done it, grandma!

Espoo, 18.03.2016

Anatoly Solovyev

CONTENTS

ABBREVIATIONS

6LoWPAN	IPv6 over Low-Power Wireless Personal Area Network
AIDC	Automatic Identification and Data Capture
ANSI/ISA	International Society for Automation
CC	Cloud Computing
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CMCR	The Central Monitoring and Control Room
CMCS	The Central Monitoring and Control System
CoAP	Constrained Application Protocol
CoRE	Constrained RESTful Environments
CPS	Cyber-Physical Systems
CS	Computer Science
CSA	The Cloud Security Alliance
CSMA	Carrier Sense Medium Access
CSP	Cloud Service Provider
CYPROS	Cyber-Physical Production Systems
DaaS	Data as a Service
DCS	Distributed Control System
EIS	Embedded Internet System
EFM	Electric Field Mapping
ERP	Enterprise Resource Planning
ETSI	European Telecommunications Standards Institute
FCS	Fieldbus Control System
FDI	Field Device Integration
FDMA	Frequency-Division Multiple Access
HMI	Human-Machine Interface
HTTP	HyperText Transfer Protocol
IaaS	Infrastructure as a Service
IAB	The Internet Architecture Board
ICS	Industrial Control System

ICT	Information and Communication Technologies
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IESG	The Internet Engineering Steering Group
IETF	Internet Engineering Task Force
IIC	Industrial Internet Consortium
IoS	Internet of Services
IIoT	Industrial Internet of Things
IoT	Internet of Things
IP	Internet Protocol
IPS	Indoor Positioning System
IRTF	Internet Research Task Force
ISO	International Organisation for Standardization
ISoc	Internet Society
ITU	International Telecommunication Union
KPI	Key Performance Indicators
LR-WPAN	Low-Rate Wireless Personal Area Networks
MaaS	Metal as a Service
MES	Manufacturing Execution System
MST	Manufacturing Science and Technology
MTU	Master Terminal Unit
NFC	Near Field Communication
OIC	Open Interconnect Consortium
OPC	OLE for Process Control
OPC UA	OPen Connectivity Unified Architecture
PaaS	Platform as a Service
PERA	Purdue Enterprise Reference Architecture
PLC	Programmable Logic Controller
PTT	Push-To-Talk
QoS	Quality-of-Service
RaaS	Routing as a Service
RFID	Radio Frequency Identification

RRI	Reader to Reader Interference
RTI	Reader to Tag Interference
RTU	Remote Terminal Unit
SaaS	Software as a Service
SCADA	Supervised Control And Data Acquisition
SecaaS	Security as a Service
SIG	Bluetooth Special Interest Group
SM	Smart Manufacturing
SMLC	Smart Manufacturing Leadership Coalition
SOA	Service-Oriented Architectures
TDMA	Time-Division Multiple Access
UDP	User Datagram Protocol
UID	User Interface Description
UIP	User Interface Plug-In
VoIP	Voice over IP
VPN	Virtual Private Network
VPS	Virtual Private Server
WfaaS	Workflow as a Service
WSN	Wireless Sensor Networks
XaaS	Anything as a Service

1. Introduction

Process automation nowadays is at the turning point of its history. Traditional automation techniques and solutions rapidly become more complex in their algorithms, organization and implementation. This downgrades further advantage gain in effectiveness and profitability. Thus, the industry requires the next qualitative leap not only in technology, but also in the paradigm of thinking and addressing arising and existing challenges, of the way we do business.

This need has resulted in several road maps for the future of the process automation. One of the most promising vision declares intensive merging of previously rather hierarchically separate areas of the whole business cycle from manufacturing to management and further to defining business strategy. The vision states interconnections of all company units at all levels with informational flows available worldwide on-demand. Moreover, those informational interconnections tangle with stronger interactions the company with its suppliers, customers and service companies. Ability to communicate and the on-line access to data via the Internet add the intelligence to the business.

This vision has appeared almost simultaneously at different places around the world and originated from different industries. Hence, it has a variety of names: Internet of Things, Industrial Internet, Industry 4.0, and many others. Whatever the name is, the desirable outcome is to change the point of view for improved results in business, production control and management.

As every new break-through production ideology, the Industrial Internet is surrounded with suspiciousness from the representatives of the Industry. They do not fully understand what it is, how it is to be applied and what actual benefits are possible. This is due to the aggressive marketing of the service providers, that try to show their products as an ultimate solution. The truth, as always, is somewhere between.

There are many available successful case studies of the Industrial Internet application at the industrial premises. However, the young age of the technology limit the number of described industrial areas and processes. This keep many companies from investing into updating their facilities to a new paradigm.

The aim of my thesis is to create a scenario for the Industrial Internet application at the concentration plant. This scenario should explain the operating company, how they should use the Industrial Internet to maximize their benefits and improve overall production effectiveness.

In the literature review part, I give a brief outline of the modern state-of-art process automation. Then I describe research and development projects of the Industrial Internet. After that, I give a description of the fundamental technology of the new automation vision. Finally, I show some success stories from the companies that have applied the Industrial Internet to their businesses.

In the practical part, at first, I state the description of the mineral concentration plant under consideration. Then, in the next section, I describe the Industrial Internet application scenario. In the following section technical guidelines for the system implementation are given. Also, in the concluding part of the thesis the future direction of research work are discussed.

LITERATURE REVIEW

2. State of process automation

A modern industrial process automation system follows a reference model for decision making and a control hierarchy (Figure 1) known as PERA (Purdue Enterprise Reference Architecture) [1]. This architecture was adopted by ANSI/ISA-95 standard [2], which has accumulated credence within the industry [3]. Often the model is represented by a so-called automation pyramid to emphasize the hierarchical nature (Figure 2).

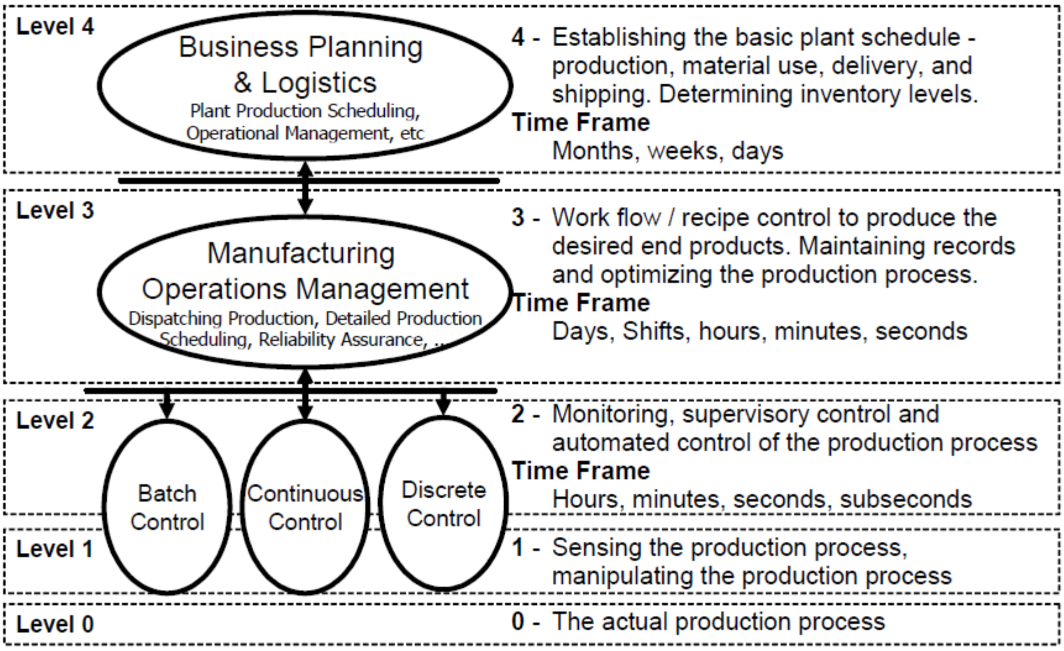

Figure 1. Purdue Enterprise Reference Architecture [1]

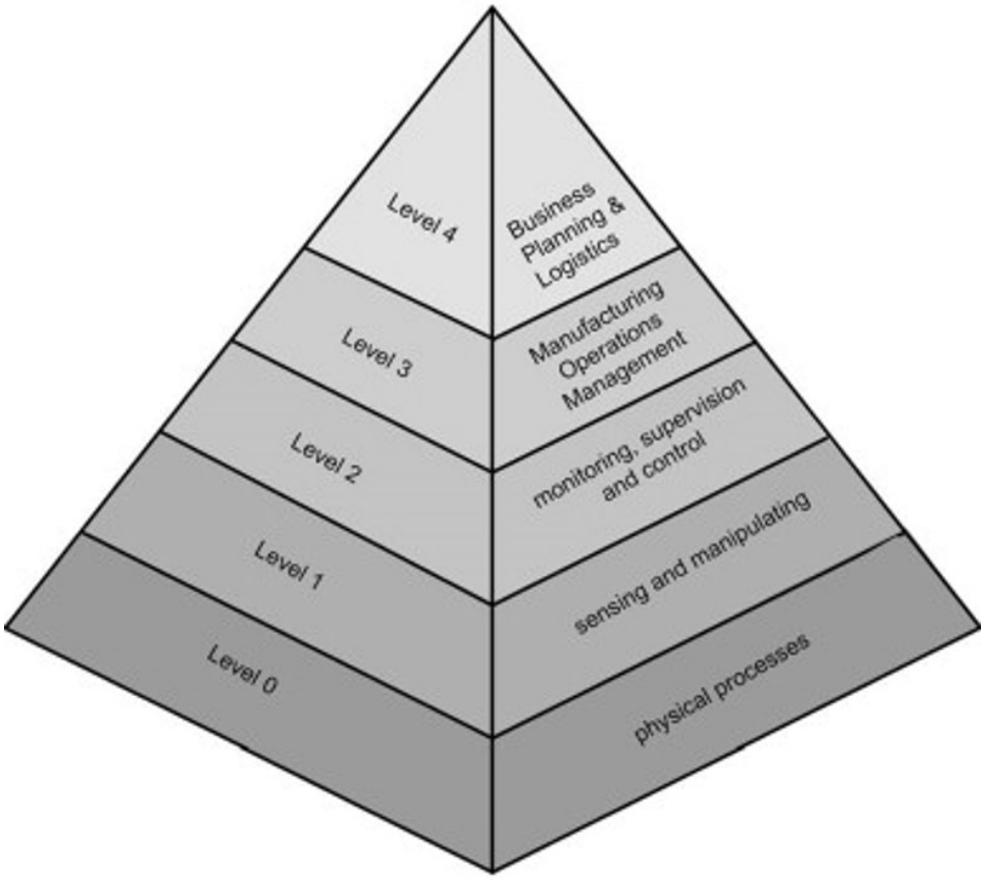

Figure 2. Automation pyramid [4]

Furthermore every level may be illustrated by a system (or systems) corresponding to the denoted function (Figure 3):

- Level 4. Business planning and logistics – Enterprise Resource Planning (ERP)
- Level 3. Manufacturing operations management – Manufacturing Execution System (MES)
- Level 2. Monitoring, supervising and control – Supervised Control And Data Acquisition (SCADA), Distributed Control System (DCS), Human-Machine Interface (HMI), Programmable Logic Controller (PLC)
- Level 1. Sensing and manipulating – sensors, actuators and other instrumentation.

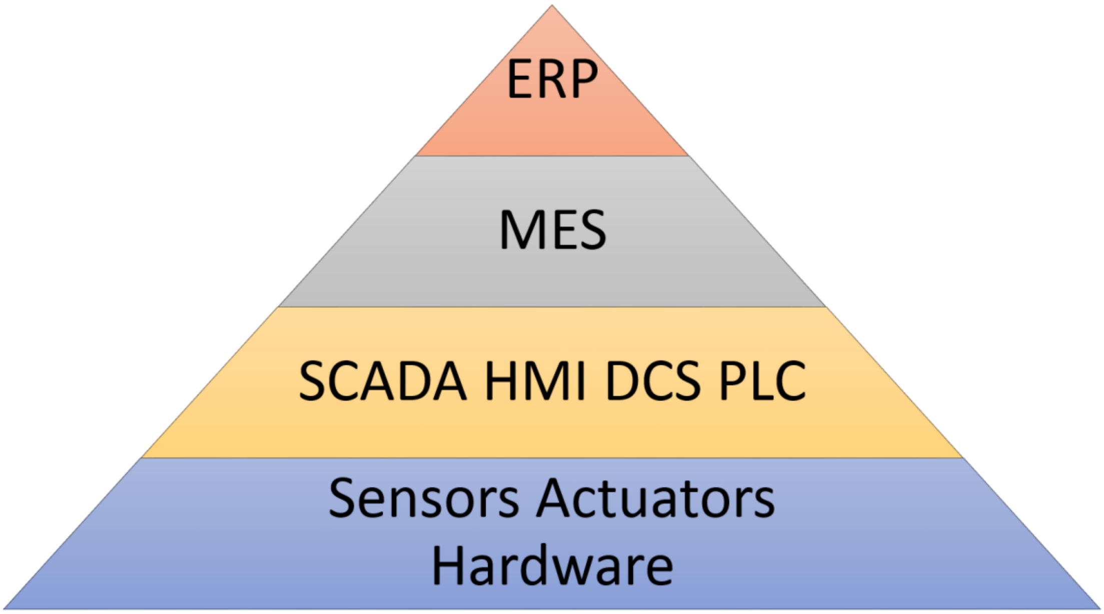

Figure 3. Systems of the automation pyramid

ERP is a business management system that integrates business functions by processing information for optimized resource utilization. Whilst it operates on the enterprise level and concentrates on managing business activities, MES is targeted at managing and monitoring actual production process at the shop floor [5]. According to the Manufacturing Enterprise Solution Association (MESA International), MES is "a dynamic information system that drives effective execution of manufacturing operations" [6]. One of its roles is to link ERP system to the control of the manufacturing process with the Industrial Control System (ICS) [7], that acquires information about the process via sensors and control it with actuators. The common ICSs are SCADA, DCS and PLC-based control system configurations.

A SCADA system is used to collect data from a geographically distributed process and assets (pipelines, power grids, railway systems) to a single control center in order to monitor the process, to present the data to the end user and to perform a control action in a centralized manner. It consists of an HMI, a Master Terminal Unit (MTU), a Remote Terminal Unit (RTU) and a long distance communication media [8]. Alternatively, RTUs may be replaced with PLCs in order to achieve optimal functionality and better cost effectiveness. A DCS, similarly, encapsulates PLC based control sub-systems of different local processes under single supervisory level providing data acquisition and representation via HMI. This type of ICS is widely used within process industries [9]. Due to continuous development of technology, boundary between these two systems in architecture and functionality has become subtle [10]. However, they possess fundamental differences that allow to separate a DCS and a SCADA (Table 1). The usage of separate PLCs is another option to control equipment and processes, especially the discrete ones. Those PLCs may be based on specific controller solutions or industrial computers.

Table 1. Differences between DCS and SCADA systems [11]

DCS	SCADA
Process driven	Event driven
Small geographic areas	Large geographic areas
Suited to large, integrated systems such as chemical processing and electricity generation and utility distribution	Suited to multiple independent systems such as discrete manufacturing
Good data quality and media reliability	Poor data quality and media reliability
Powerful, closed-loop control hardware	Power efficient hardware, often focused on binary signal detection

To provide sustainable operation of the pyramid there is a demand for a network connection delivering reliable information flow between the layers as well as within a single layer. To fulfill this request there were introduced various protocols, model types, standards and bus types composing an industrial network. All that have led to the device heterogeneity (Figure 4). Field devices are connected to the control level with so-called fieldbuses. Currently, the major and most wildly used fieldbus standards namely are Modbus, PROFIBUS, Ethernet/IP, Foundation Fieldbus, HART, INTERBUS [11, 13]. Communication on higher levels is performed via Ethernet, OPC and OPC UA standards.

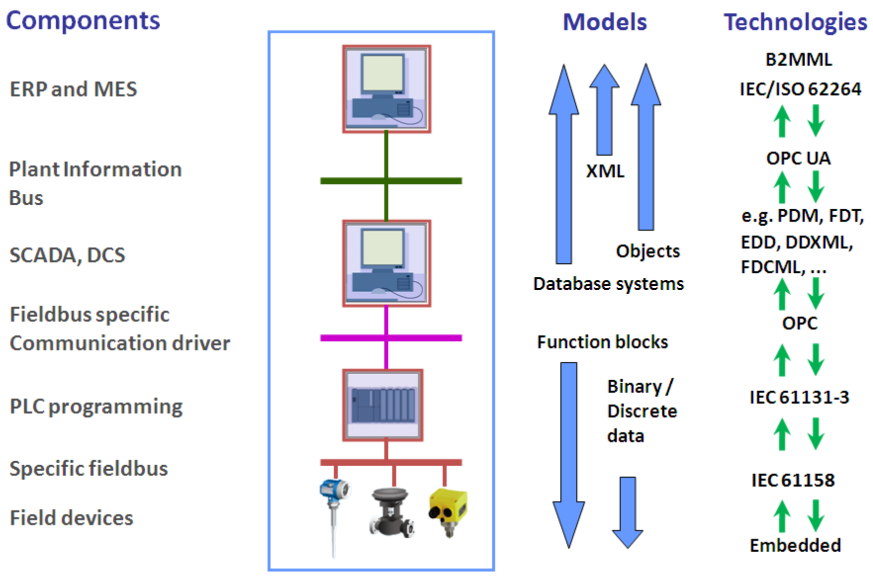

Figure 4. Device heterogenity [12]

Further improvement of network capabilities of industrial process automation systems has become one of the major trends in process automation development. First of all, network approaching closer to the field devices by embedding PLCs in actuators (as in Fieldbus Control System – FCS, Figure 5). Moreover, growing attention is paid to the use of wireless communication for fieldbus and higher levels [15].

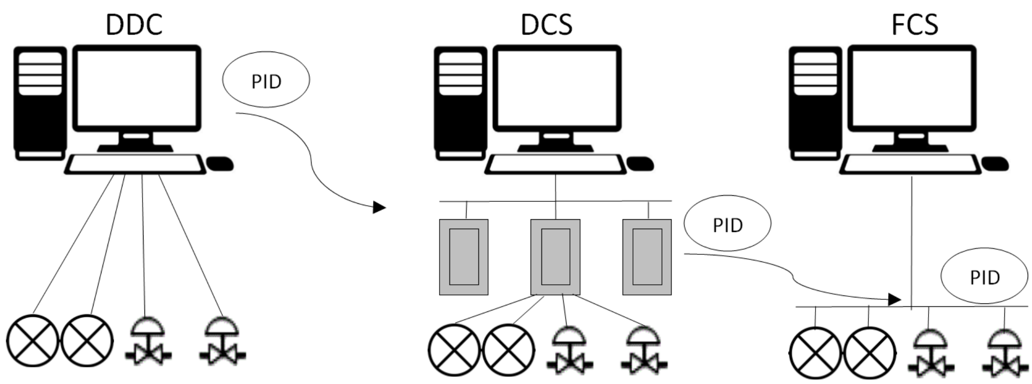

Figure 5. Control system development, adapted from [14]

Another trend is to migrate from the automation pyramid to an automation based on Cyber-physical systems (CPS) (Figure 6) and to a wider use of field devices with extended network capabilities.

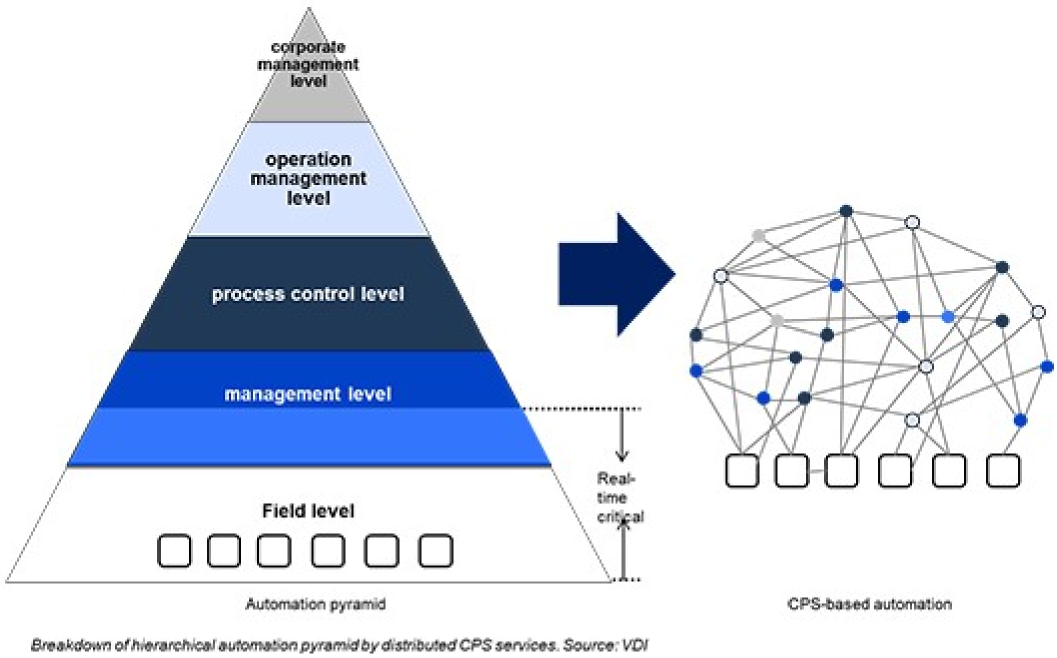

Figure 6. Transition from the automation pyramid to the CPS [16]

However, wider application of information networks for ICS has led to increased vulnerabilities in cyber security of the enterprise [17]. And it becomes even more challenging due to design and operational differences of the ICS and the traditional business IT networks [18].

These changes founded a transition to the next step of process automation evolution generally named as Industrial Internet.

3. Industrial Internet Research and Development initiatives

As this new evolutionary step of process automation is believed to be a source of remarkable income [19], in recent years different research and development programs were initiated all around the world. The most significant and well-known ones are Industrie 4.0 and SmartFactory in Germany, Industrial Internet Consortium and Smart Manufacturing Leadership Coalition (both originated in the USA). Despite of being insignificantly different in their approaches to the phenomena, they concur with a vision, that even partial (Figure 7) implementing of the new paradigm will benefit both the industry and customers [20].

What if... Potential Performance Gains in Key Sectors

Industry	Segment	Type of Savings	Estimated Value Over 15 Years (Billion nominal US dollars)
Aviation	Commercial	1% Fuel Savings	$30B
Power	Gas-fired Generation	1% Fuel Savings	$66B
Healthcare	System-wide	1% Reduction in System Inefficiency	$63B
Rail	Freight	1% Reduction in System Inefficiency	$27B
Oil & Gas	Exploration & Development	1% Reduction in Capital Expenditures	$90B

Note: Illustrative examples based on potential one percent savings applied across specific global industry sectors.
Source: GE estimates

Figure 7. Estimated performance gain of 1% savings across industries [29]

3.1. Industrie 4.0

Industrie 4.0 (or often in the English language articles and references - Industry 4.0) is a project of the German government and a term denoting the transition from embedded systems to cyber-physical systems and further to an Internet of Things, Data and Services [21]. This name was first used during the Hanover fare in 2011 [22] and is supposed to name the fourth industrial revolution, that is believed to be already evolving, represented by the transition mentioned above. The first revolution was due to steam and hydro powered manufacturing in the end of the 18^{th} century. Then came the second revolution by introducing electric powered mass-production and conveyor lines in the end of the 19th century. Later, the third revolution, electronics and IT driven, followed in 1970s.

The project is a part of the High-Tech Strategy 2020 Action plan by the German government and is supported by other adjacent and complimentary projects and programs, such as Agenda CPS, ICT 2020 (IT systems for Industrie 4.0), Autonomics for Industrie 4.0, CYPROS (cyber-physical production systems) and RES-COM [21]. It has merged remarkable efforts of academia and industry. In 2011, the Industry-science research alliance and acatech (the National Academy of Science and Engineering) established the Industrie 4.0 Working group for guiding the development of the project [21]. Finally, launched in 2013 the Platform Industrie 4.0 became an important link between researchers, companies, politics and employee [21].

The project foresees the future of industry as interconnected technical systems with intelligence provided by CPS, so that they operate in a self-controlled manner. Those systems are called smart systems. According to [23] the following approaches describe conception of the Industrie 4.0:

- Cyber-physical systems
- Internet technology
- Components as information carriers
- Holistic safety including privacy and knowledge protection

In [24], besides giving a clear definition of the Industrie 4.0, derived design principles were introduced. They are:

- Interoperability
- Virtualization
- Decentralization
- Real-time capability
- Service orientation
- Modularity

Focus of the Industrie 4.0 is on adding intelligence to the industry and merging it with the Internet so to obtain smart products, procedures and processes [25]. This is supposed to result in emerging CPS platforms that will support collaboration between industrial and associated business networks and by the means of services will establish connection between people, objects and systems (Figure 8) [25].

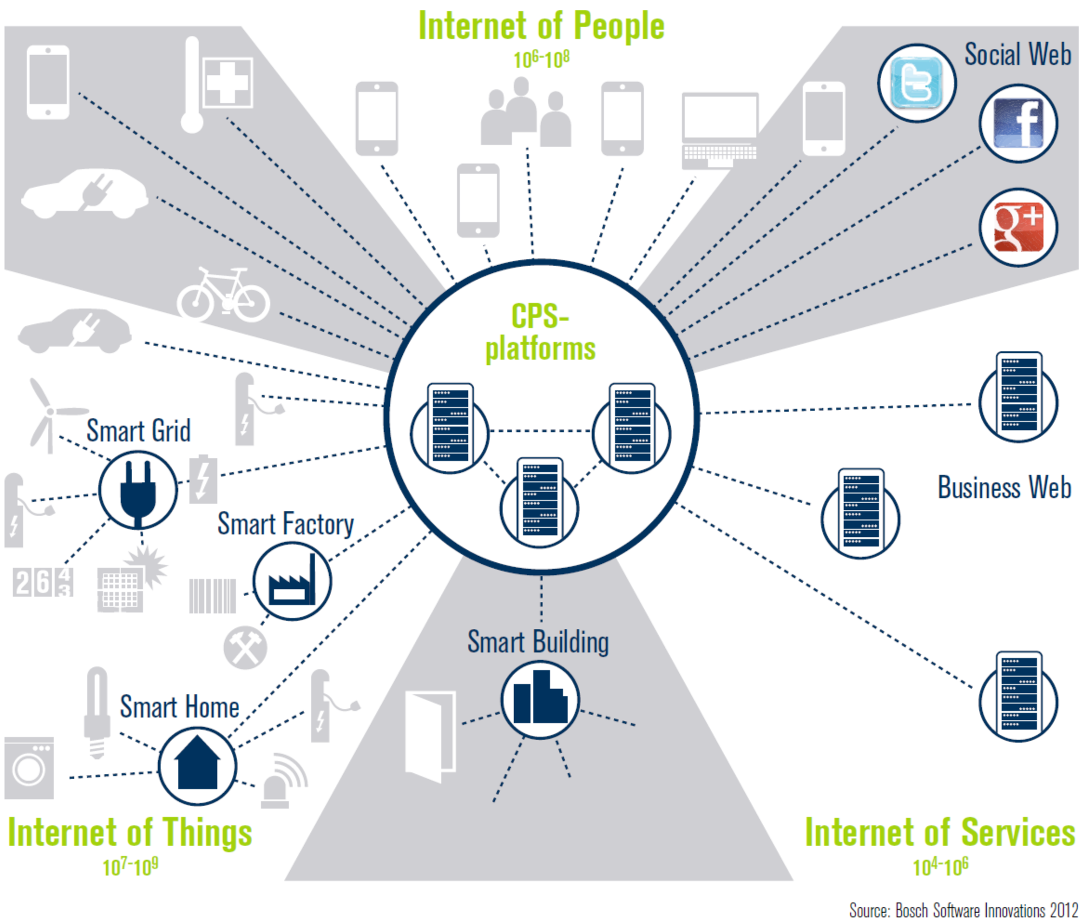

Figure 8. The internet of things and Services - Networking people, objects and systems [25]

This view corresponds to the one of the Industrial Internet paradigm.

3.2. Industrial Internet

Industrial internet is the term introduced by General Electric R&D Division [26] to describe the new step in industry and process automation evolution. Sometimes it is used in the form of the Industrial Internet (of Things) or IIoT [27], thus illustrating its relation to the Internet of Things (IoT). Recently, in March 2014, AT&T, Cisco, GE, Intel and IBM have founded the Industrial Internet Consortium "to accelerate growth of the Industrial Internet by identifying, assembling and promoting best practices" [28]. As of May 2015 the Consortium unites 157 members from 21 countries.

IIC evaluation of the change of the paradigm as a revolution is similar to the one of I40. However, they are significantly different in denoting number of revolutions and their driving force. From General Electric's point of view Industrial internet is the third "wave of innovation and changes" [29]. The first wave is called Industrial revolution and is divided into two sequential stages: the stage of commercialized steam engine and the stage of the internal combustion engine, electricity and other machinery. Thus, the first revolution of IIC corresponds to the first two revolutions of I40. The second wave is called Internet revolution and is due to the first main frame computers and early networks at the starting stage and open networks and World Wide Web at the latter stage [29]. By that mean, it is partially overlapping the third Industrial revolution. The last wave is Industrial internet revolution and it possesses a driving force identical to the Industrie 4.0.

From the Industrial internet point of view the new technological revolution will be driven by connecting intelligent machines , advanced analytics and people at work (Figure 9) [30].

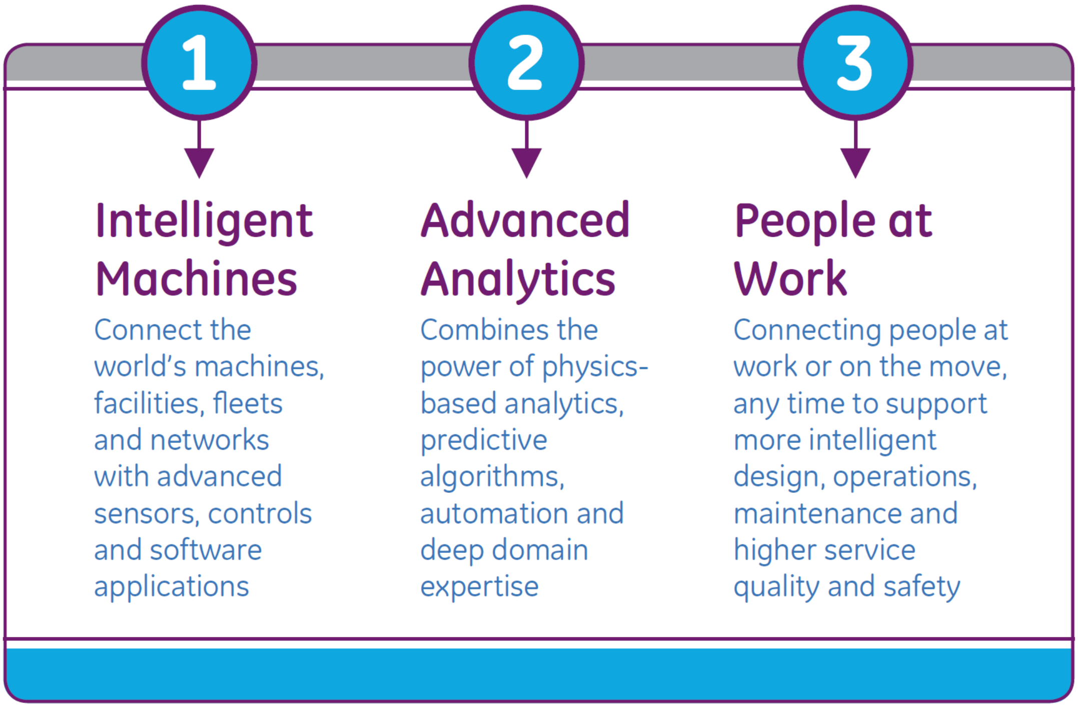

Figure 9. Key elements of the Industrial Internet [29]

This connection and proper work of the new industrial network is obtained by utilization of several recent advantages in technology and production philosophy [31]. Namely they are:

- Big Data – to manage continuously increasing volume of data produced as a result of different industrial and business processes;
- The Internet of Things – to connect sensor, actuators and many other different types of already existing and future intelligent devices as well as other equipment, products and even the whole factories;
- Growing data analytics capabilities – to mine and analyze the Big Data generated by connected industrial and business entities;
- Moving to the heart of a business the equipment itself in order to acquire an economic impact.

Despite the fact that Industrial Internet is applicable to the industry in general, its main fields of interest are power generation and distribution, healthcare, mining, aviation, oil and gas, transportation and manufacturing [31]. Revolutionizing of the manufacturing in accordance to new trends in technology is also the main aim of Smart Manufacturing Leadership Coalition (SMLC).

3.3. Smart Manufacturing

Smart manufacturing (SM) is a set of practices to integrate data from the individual factories and on enterprise-wide level and to merge it with computer models and simulations in order to obtain manufacturing intelligence. This in its turn will lead to process and product innovations that will reshape the manufacturing itself by producing cheaper goods satisfying individual needs of customers [32]. To achieve optimal performance SM utilizes information that is "available when it is needed, where is needed and in the form it is the most useful" [33].

SMLC is a non-profit organization consisting manufacturing practitioners, suppliers, and technology companies; manufacturing consortia; universities; government agencies and laboratories [34]. The goal of the organization is to contribute adoption of SM across the US industry by creating the Open SM platform – networked IT infrastructure [35].

This platform foundation is of two main components – workflow and cloud computing [36]. It is designed as Workflow as a Service (WfaaS) software with service-oriented and management environment [33]. The expected capabilities of the platform are [37]:

- substantially reducing development and deployment costs for manufacturing oriented modeling and simulation
- reducing costs for IT infrastructure
- access to Smart Manufacturing applications and new models for innovation
- an enterprise digital layer for applied manufacturing
- intelligence and applied performance metrics
- test bed demonstrations
- dynamic involvement of small, medium and large enterprises.

Although those initiatives visualize the new approach to the industry in a various manner, it consists of equivalent components.

4. Fundamentals of the Industrial Internet

For successful implementation of the vision of the Industrial Internet to the industrial sites and its further development it needs a robust foundation. The Industrial Internet bases on several key paradigm that are advanced Internet technologies that are commonly referred to as the Future Internet, CPS and standards. Altogether, they provide a stable momentum for steady adoption of the new industrial vision to the companies.

4.1. The Future Internet

Modern internet has faced a challenging contradiction between its data-exchange design of 1970s and contemporary requirements of business and industry. This situation has led to introduction of the concept of the Future Internet that could be elucidated with three other concepts, namely: the Internet of Things (IoT), the Internet of Services (IoS) and the Cloud Computing (CC) [38].

Internet of Things

According to the Cisco Internet Business Solutions Group (Cisco IBSG), sometime between 2008 and 2009 the number of devices or "things" connected to the Internet all around the world has exceeded the number of the world population of the mankind (Figure 10) [43]. This occasion has marked the starting point of the Internet of Things existence.

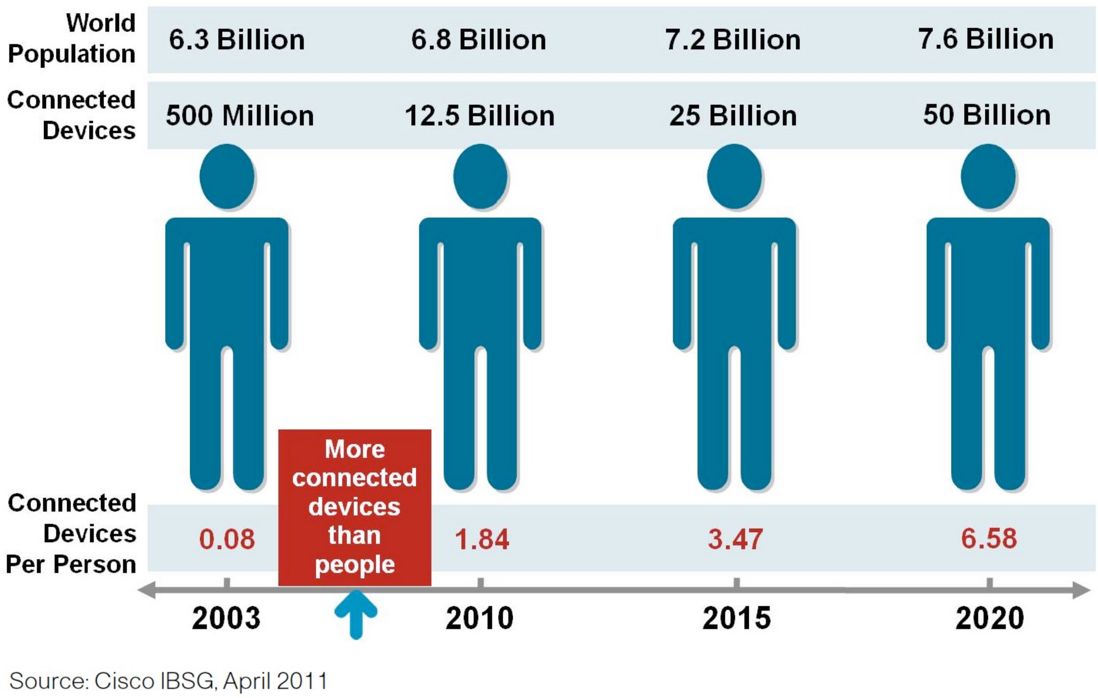

Figure 10. The emergence of the IoT [43]

The term "the Internet of Things" originates from the Auto-ID center at the Massachusetts Institute of technology (MIT) [39] and was coined by Kevin Ashton, who introduced it in his presentation at Procter & Gamble company in 1998 [40]. Originally, it meant the widespread utilization of Radio Frequency Identification (RFID) tags for marketing, yet alternative applications start to appear with the further technological and ideological development [46]. However, since late 90s there is no clear definition of the IoT. That is due to different approaches for this paradigm: "Internet", "Things", and "Semantic" -oriented visions [41]. Moreover, various organization explain the IoT in the divergent manner (Table 2) [42].

Table 2. Definitions of the IoT [42]

Organization	Definition
CCSA	A network, which can collect information from the physical world or control the physical world objects through various deployed devices with capability of perception, computation, execution and communication, and support communications between human and things or between things by transmitting, classifying and processing information
ITU-T	A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies
EU FP7 CASAGRAS	A global network infrastructure, linking physical and virtual objects through the exploitation of data capture and communication capabilities
IETF	A world-wide network of interconnected objects uniquely addressable based on standard communication protocols

In spite of IoT disambiguation still being in progress, this research and development area is at the peak of the Gartner emerging technologies hype cycle (Figure 11). It is expected that the IoT will have wide adoption and will create a profitable market in the next 5 to 10 years [44]. To further illustrate the importance of the IoT for the industrial and business world it is worth noting that the National Intelligence Council recognized the IoT as one of the disruptive civil technologies with potential impact on the interests of the United States out to 2025 [45].

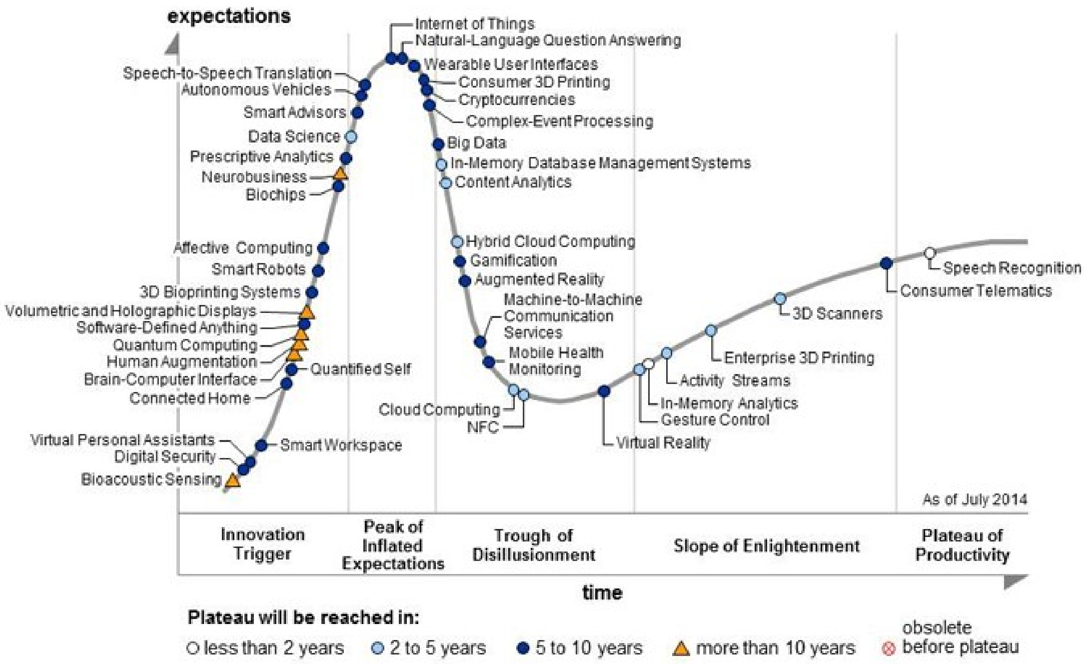

Figure 11. Gartner emerging technologies hype cycle 2014 [44]

General IoT architecture consists of three components [47]: a *perception layer* is responsible for identification of “things” and collection of the information they provide; a *network layer* is a communication media between the perception and service layers and at the *service layer* information processing applications are executed.

RFID and wireless sensor networks (WSN) are vital elements of the IoT in general and its perception layer in particular and thus the development of these technologies gathers close attention of the research and engineering community [48]. Simplicity of the RFID system (Figure 12) also assists its broader adoption in the industry. The latest advancements in smart devices and the introduction of Near Field Communication (NFC) to smartphones allow easy interaction with some RFID-tags without any need for a specially designed reader [48].

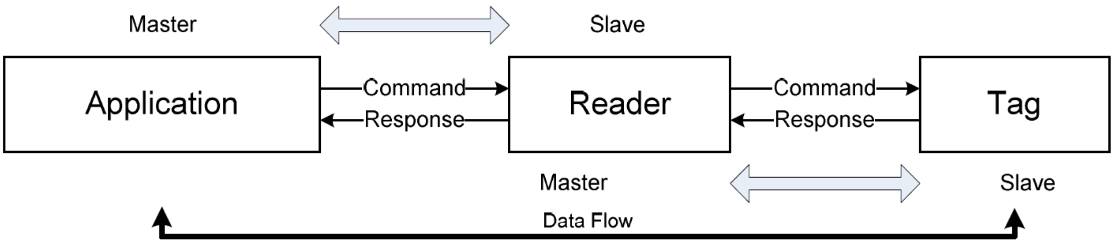

Figure 12. RFID system [49]

Although the IoT proposes remarkable possibilities, it also accentuate the security concerns. As it collects a diverse information from and about people, several measures must be implemented to prevent unauthorized access to the data as well as possible leakage of personal information, especially in the medical-related applications [50]. Hence, security became one of the subject of interest for further research among others that are [51]: massive scaling, architecture and dependencies, creating knowledge and Big Data, robustness, openness, privacy, humans in the loop.

Internet of Services

Another vision of the emerging technological paradigm, which compliments the Internet of Things in the Future Internet concept, is the Internet of Services (IoS). The IoS, or Web 3.0, includes services generated by users and sensor- and device-oriented services [52]. Moreover, this vision alters design and implementation of the ICT systems and applications as they become composed of distributed services and not of traditional programming components [53].

The IoS (Figure 13) is a result of Web 2.0 and Service-Oriented Architectures (SOA) combination: Web 2.0 represents collection of applications in the Web and SOA describes publicly available services that enclose the application logic and share the uniformly defined interface [54].

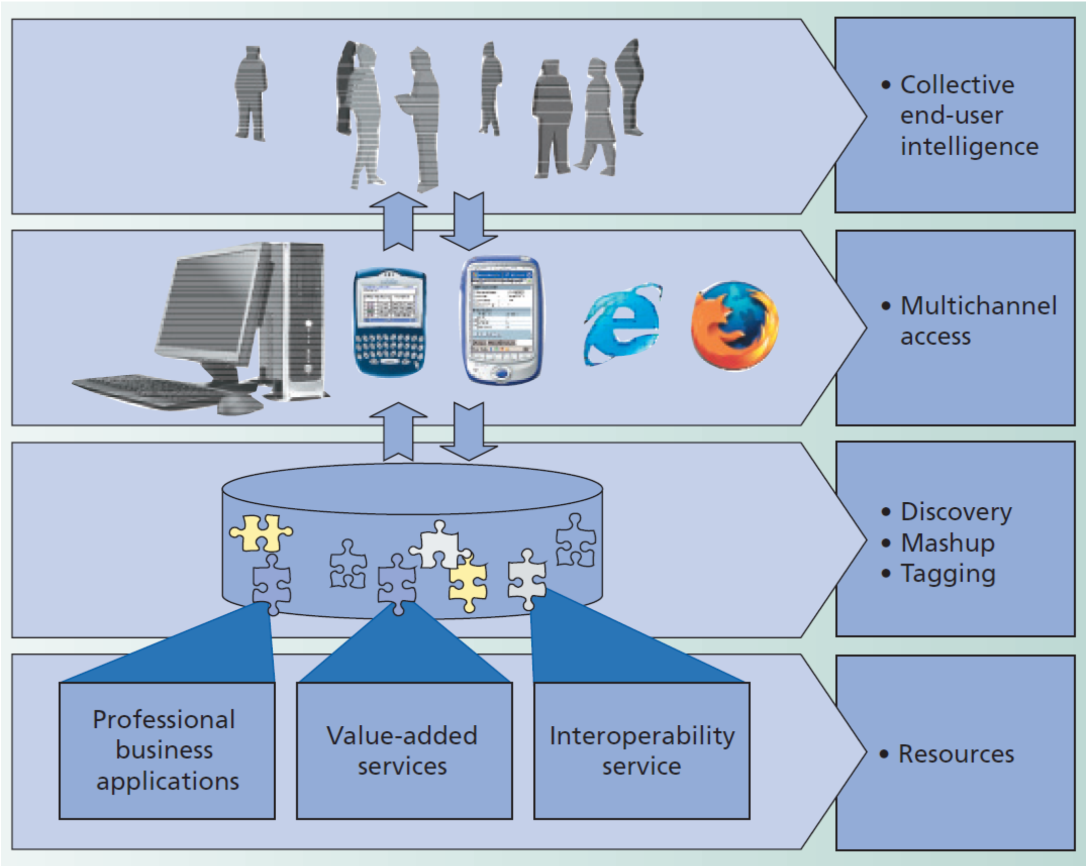

Figure 13. The basic architecture of IoS [54]

The vision of the IoS bases on the set of services [55] that are usually illustrated as encapsulated (Figure 14):

- Business service - business activities provided by a service provider to a service consumer to create a value for the consumer;
- e-Service – transaction conducted through the Internet;
- and Web Service – e-services that are made available for consumers using Web-based protocols or Web-based programs

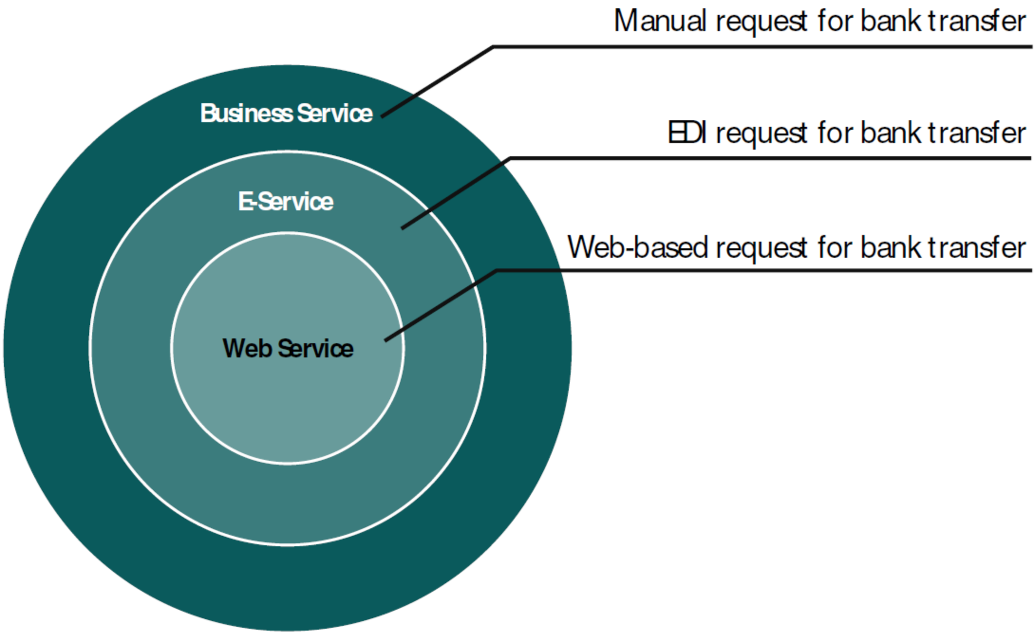

Figure 14. Example of the encapsulation of the services [55]

Cloud computing

The third component of the Future Internet helps to bring the IoS paradigm to the real world together with other technological and business innovations like Business Networks, Big Data Analytics and Mobility [56]. It emerged rapidly around 2008 [57] and followed a shift in the vision of computing from having a personal computation device to take the advantage of shared resources [58].

National Institute of Standards and Technology (NIST) of the US Department of Commerce defines cloud computing as "*a model for enabling 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. This cloud model is composed of five essential characteristics, three service models, and four deployment models*" [59]. Figure 15 illustrates the general cloud computing architecture.

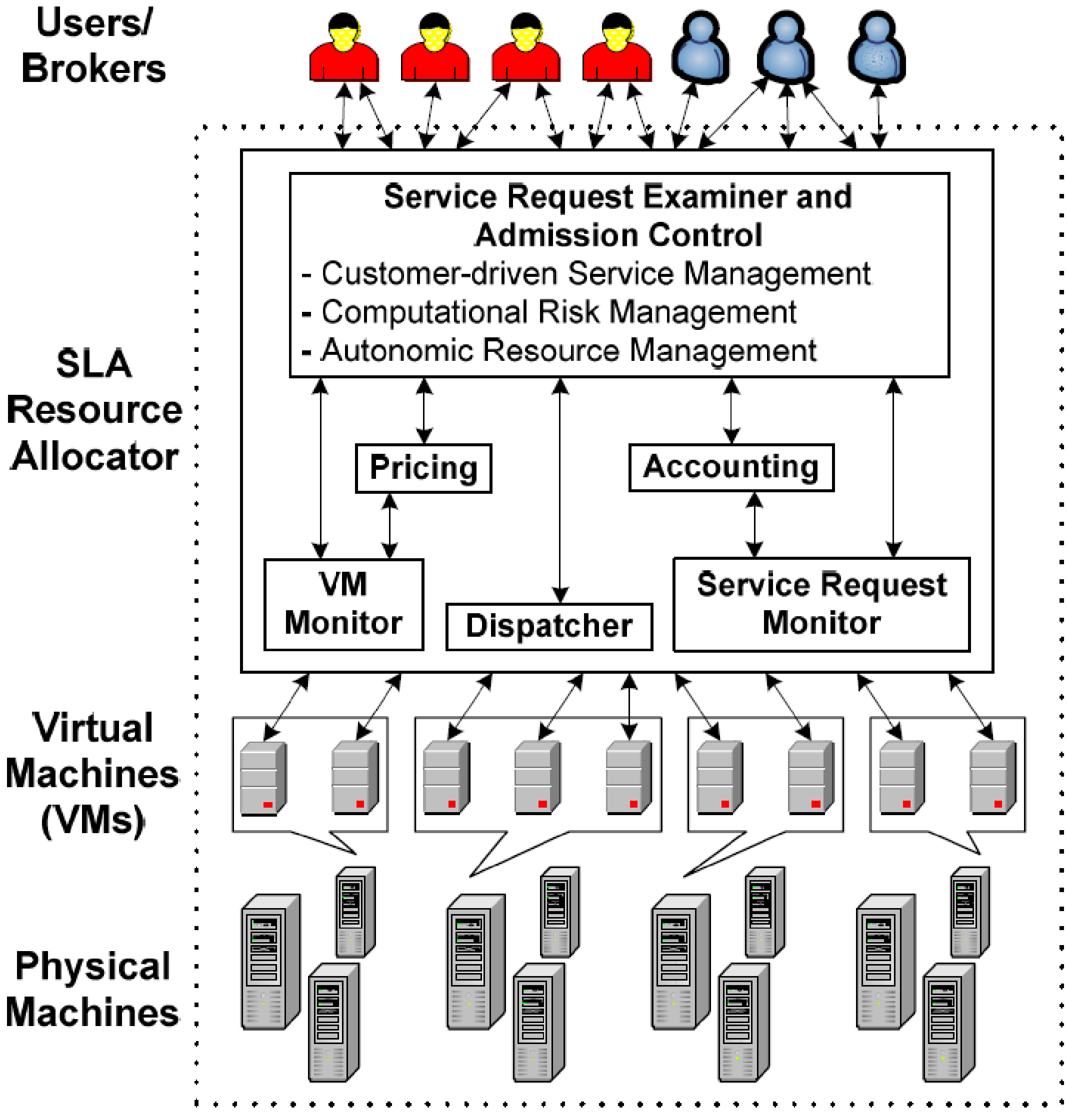

Figure 15. General cloud computing architecture [60]

Essential characteristics of cloud computing, as proposed by the NIST model, are [61]:

- On-demand self-service – services and resources of the cloud are allocated to the customers on their demand through a Web service without direct interaction with Cloud Service Provider (CSP)
- Broad (ubiquitous) network access – customer must be able to access data and applications, as well as services, located in the cloud using the standard protocols and different types of devices

- Resource pooling – the resources shared by pooling have a mapping between virtual and physical entities and provide the information of their location to the customers.
- Rapid elasticity – resources are scaled in accordance with customer request in a rapid and elastic manner
- Measured service – the usage of resources is measured and passed to the CSP and customer in the form of the report, thus supporting pay-as-you-use business model

The Cloud Security Alliance (CSA) proposed [62] additional essential property for the cloud computing, which they call a multi-tenancy – an option to use a single resource by multiple customers to achieve optimized resource utilization and the logical separation of the customers.

In modern cloud computing there are three models for service delivery in use [63]:

- Software as a Service (SaaS) – various applications are hosted in a cloud and customers access them via the Internet on pay-as-you-use basis, a business model for software distribution
- Platform as a Service (PaaS) – provides a tool, a platform and a framework as a service to help build web-based application for customers
- Infrastructure as a Service (IaaS) – offers Virtual Private Server (VPS) with the basic security, allows customers to cut their expenses for hardware and technicians.

Usually, one more service model is described – Anything as a Service (XaaS) [57]. According to that model cloud technologies are able to offer various objects as a service, and with technological evolution continues clouds will be capable of providing everything as a service. Examples of this model are Data as a Service (DaaS), Routing as a Service (RaaS), Security as a Service (SecaaS), Metal as a Service (MaaS) [57, 58].

In terms of the cloud deployment, there are three differentiated models [62]:

- Private cloud – a single organization consumes all resources of the cloud;

- Public cloud – a cloud operated by the CSP with an option to access to general public or organizations
- Community cloud – resources of the cloud are shared by the community consisting of customers and companies, that are united by the common interest
- Hybrid cloud – a union of several entities of clouds of types mentioned above, that use the same technology and are managed centrally.

Several sources differentiate also the Virtual Private Cloud deployment model [57]. It is a virtual private or semi-private cloud based on the Virtual Private Network (VPN) connectivity. This model offers higher security standards and it may exist within any kind of cloud listed previously as a private cloud.

Figure 16 illustrates the model described.

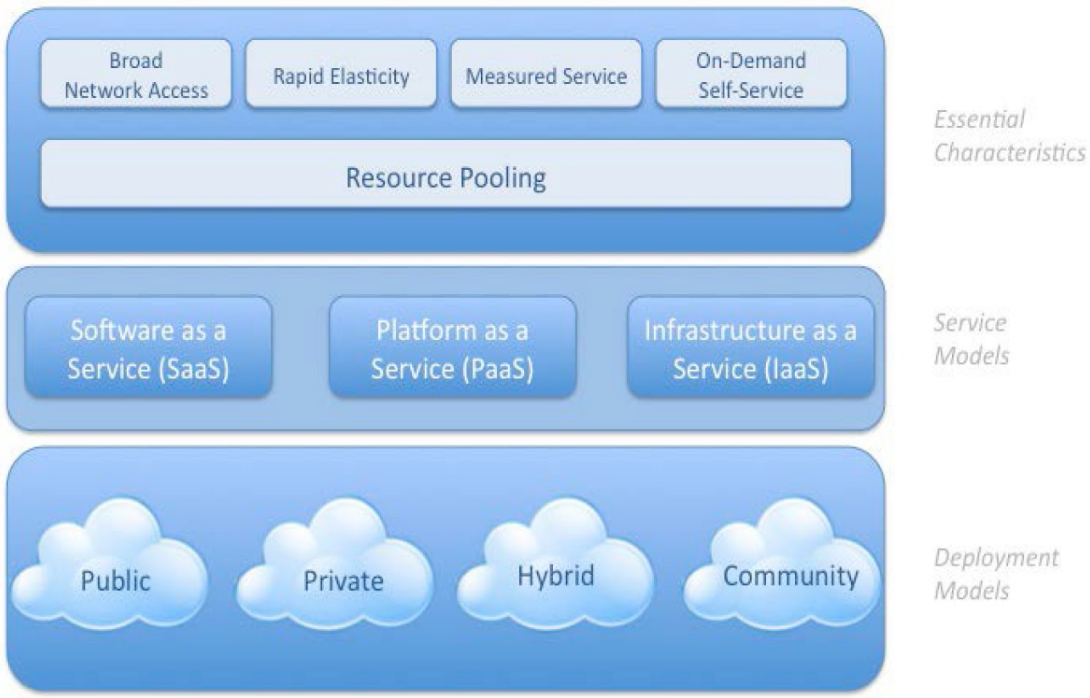

Figure 16. NIST model of cloud computing [62]

Concepts of cloud computing and the IoS are very close and they sometimes even intersect (especially in the case of SaaS), nonetheless they cannot be considered as equivalent technologies [64]: they target different user groups, have different payment policies and performance evaluation criteria. Despite being different, they create a great advantage then work together, for example Web applications are used for visualization of the cloud computing resources [61].

4.2. Cyber-physical systems

The term Cyber-physical systems or CPS describes intersection of the physical world of equipment and processes and the virtual or computational world. The term was introduced by Hellen Gill in 2006 at the National Science Foundation in the United States [65]. CPS consists of three essential concepts: communication, computation and control (Figure 17) [68].

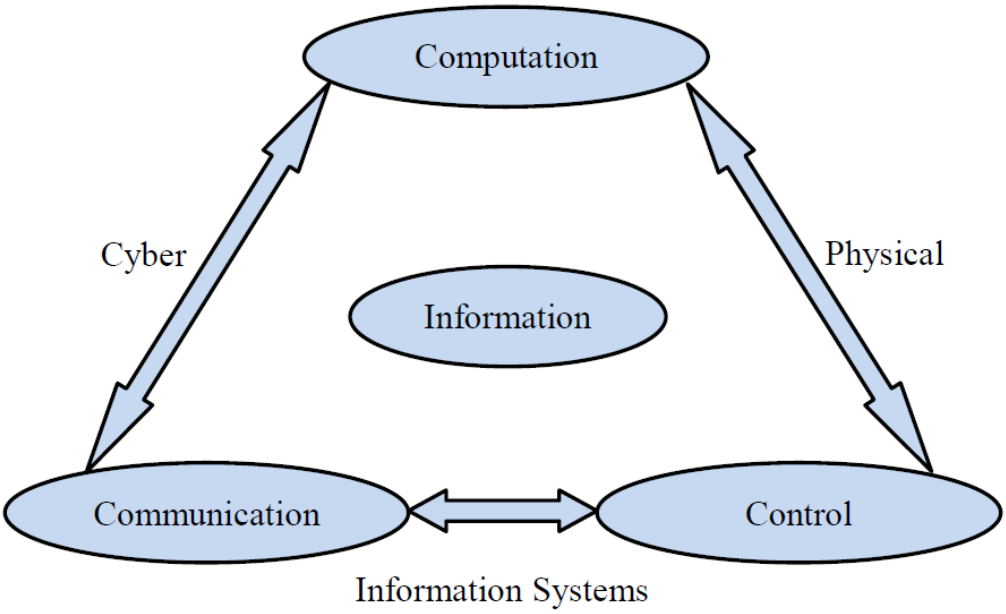

Figure 17. Concepts of CPS [63]

CPS focuses on controlling physical objects by computational entities through the communication media [66]. This is due to its evolution from common embedded systems [67]. A union of them, real-time systems, distributed control systems and controls provides a foundation for CPS of different size – from a nanoscale to geographically dispersed systems [69]. The fields of usage for CPS are avionics, robotics, electric power control, health care, defense systems, transportation vehicles and intelligent highways, process control, factory automation, efficient building energy use and environmental control and many more [68,69,70].

CPS derives the driving force for its continuous developing from such research areas as computer science (CS), Information and communication technologies (ICT) and manufacturing science and technology (MST) [71]. Due to usually performing a critical task and often in hazardous environment, operation of CPS must follow several criteria. They are dependability, safety, security, efficiency and real-time action [69]. The latter characteristic is also a distinguishing indicator to differentiate CPS and general distributed computing systems [72].

Authors of [73] propose an architecture for implementing a CPS at the physical industrial environment under the name 5C Architecture. It consists of five levels with their names following their functionality: connection, conversion, cyber, cognition and configuration (Figure 18).

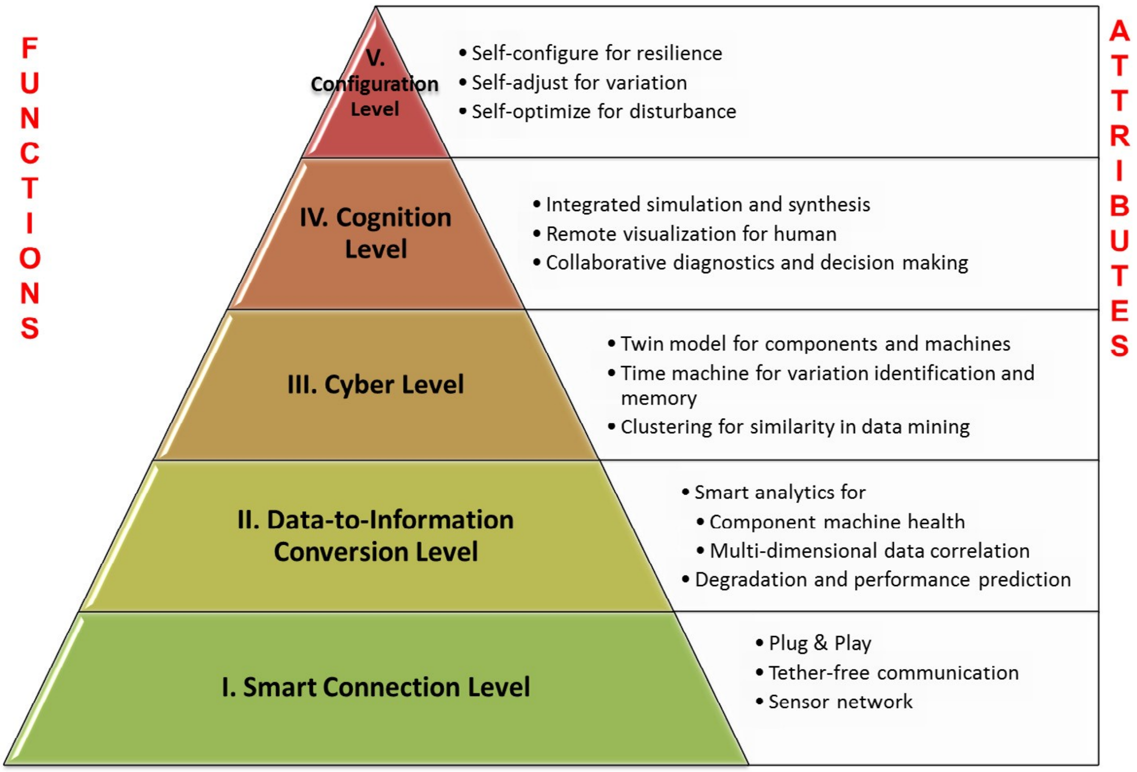

Figure 18. The 5C architecture of the CPS [73]

To support CPS a physical platform should be autonomous, perform computation, be capable of the precise control, provide sustainable communication and offer remote collaborative capabilities [68].

As in case of cloud computing and the IoS, CPS and the IoT are often considered to be synonyms [74], believed to have a fading boundary [73] or even to merge with the development of the technology [51]. Nonetheless, another vision exists stating that IoS and CPS are different concepts. One point of view is that CPS is an intersection of IoT, a software system, and an embedded system [75]. It uses a “things” interconnection, but pays more attention to the real-time and dynamic information control and information service. Also, CPS and IoT may be seen as the synonyms with granting CPS a more fundamental status as it does not state the implementation method directly [76]. Finally, relatively popular opinion is, that CPS is a link that connects the IoS and cloud computing (computational and virtual world) be the means of the IoT to the physical world of people and processes [77, 78, 79].

4.3. Design principles

Authors of [24] propose design principles for the implementation of Industrie 4.0 systems that are applicable to the Industrial Internet paradigm in general. Suggested principles are interoperability, virtualization, decentralization, real-time capability, service orientation and modularity.

Interoperability

The interoperability principle states that components of Industrial Internet systems should be able to interact with one another via “open nets and semantic descriptions” [24] notwithstanding being manufactured by various vendors. In other words, the principle states enabling role of the industry-wide accepted standards for device integration and communication.

Virtualization

In the context of design principles, virtualization means creating a virtual copy of an actual process by linking plant and simulation models to observed data received through sensors to monitor all conditions of the system. In case of an event, system notifies responsible personnel, provides them all necessary information and suggests further action steps.

Decentralization

Facing increasing request for individually manufactured products, the centralized control of the systems becomes difficult. By the means of embedded sensors and computing powers parts of Industrial Internet systems or even a single actuator may react to new information and take control actions on their own. This makes centralized planning and control obsolete.

Real-Time Capability

For seamless operation of the Industrial Internet system, it needs to obtain information, perform analytics and take control actions in real-time manner. Thus, the system will be able to reorganize its operation in case of failures or over events to minimize downtime and losses.

Service Orientation

This principle emphasizes the role of the IoS in providing services of companies, CPS and humans to other users. The range of services may vary from the company internal level to the level between companies.

Modularity

The modularity principle shows the versatility of Industrial Internet systems. In case of operational fluctuations due to change of product specifications or seasonal market variations modules of the system may be added to the system, extracted from it or replaced in Plug&Play way in order to provide optimal operation and productivity costs.

4.4. Standardization of the industrial Internet

The IoT technologies and devices play an important role in the Industrial Internet because of being the final product, which operating companies will install and apply to their factories, plants and other assets. From this and the design principle of interoperability, the need for standardization emerges, as widely adopted industrial standards are the key component of the IoT and the Industrial Internet enduring success [80]. This is due to the importance of adopted standards for emergence of the critical mass of users needed for continuous growth of the industry [82].

There are several standardization organizations operating at different levels, that actively designing a standardized view of the IoT and complementary technologies [81]. The largest international organization, formed of national standardization organizations, is International Organisation for Standardization (ISO). International Electrotechnical Commission (IEC) and International Telecommunication Union (ITU) accompany IoT related work of ISO at the international level. The standards they produce are the basis of many national technological standards.

At the European level, there are corresponding organizations: European Committee for Standardization (CEN), European Committee for Electrotechnical Standardization (CENELEC) and European Telecommunications Standards Institute (ETSI).

In addition, there is a set of organizations and communities working on the standardization and development of technologies, which create basis for Industrial Internet evolving. For example, Bluetooth Special Interest Group (SIG), HART Communication Foundation, Open Interconnect Consortium (OIC), OPC Foundation, International Society for Automation (ISA), Institute of Electrical and Electronics Engineers (IEEE), Internet Society (ISoc) that is parental organization for Internet Engineering Task Force (IETF), the Internet Architecture Board (IAB), the Internet Engineering Steering Group (IESG) and the Internet Research Task Force (IRTF), and many more.

Field Device Integration (FDI)

One of such supplementary standardization company is Field Device Integration Cooperation, LLC (a limited liability company under US law). It was founded in 2011 by FDT Group, HART Communication Foundation, OPC Foundation, PROFIBUS & PROFINET International and Fieldbus Foundation [83]. The result of its activity is an approved IEC62769 “Field Device Integration (FDI)” standard [84].

FDI is a technology for integration of field devices at an operating plant that is able to configure, diagnose and calibrate integrated devices in order to make the information from the device available at a higher level [85]. Basic technologies of FDI are the Device Package and the Common Host Components. The Device Package is a file (Table 3) issued by a manufacturer that makes it possible for the device to be integrated, and the Common Host Components is a software of the host system.

Table 3. Content of a FDI Device package [86]

Device Definition	Description of all device parameters, including label, data type and localized help text
Business Logic	Wizards that step a user through the processes. Conditionals to hide internal dependencies
User Interface Description (UID) “Device Pages”	Visualization graphics and task/role-based hierarchical menu system
User Interface Plug-In (UIP) “Plug-In”	Optional software component for setup and diagnostics not available in the device
Attachments	Other optional integration files and manuals etc.

OPC UA

Information model of the OPC Unified Architecture (OPC UA) is a basis for the FDI architecture [85]. OPC UA stands for the OPen Connectivity Unified Architecture. It is the IEC standard (IEC 62541) for secure, reliable and vendor-independent interconnectivity in the real-time manner for state-of-art industrial automation systems [87, 88]. OPC UA specification consists of 11 parts [89]. They give an overview of the standard, clarify security model, define abstract services, address space and information models, the mapping of the abstract services to a concrete technology, specify profiles for clients and servers, data and historical access, alarms and conditions, and programs.

The architecture of the OPC UA is complex and its operational range varies from embedded to enterprise systems with different types and speeds of data transferring (Figure 18). Hence, performance becomes one of the main requirements for it [90].

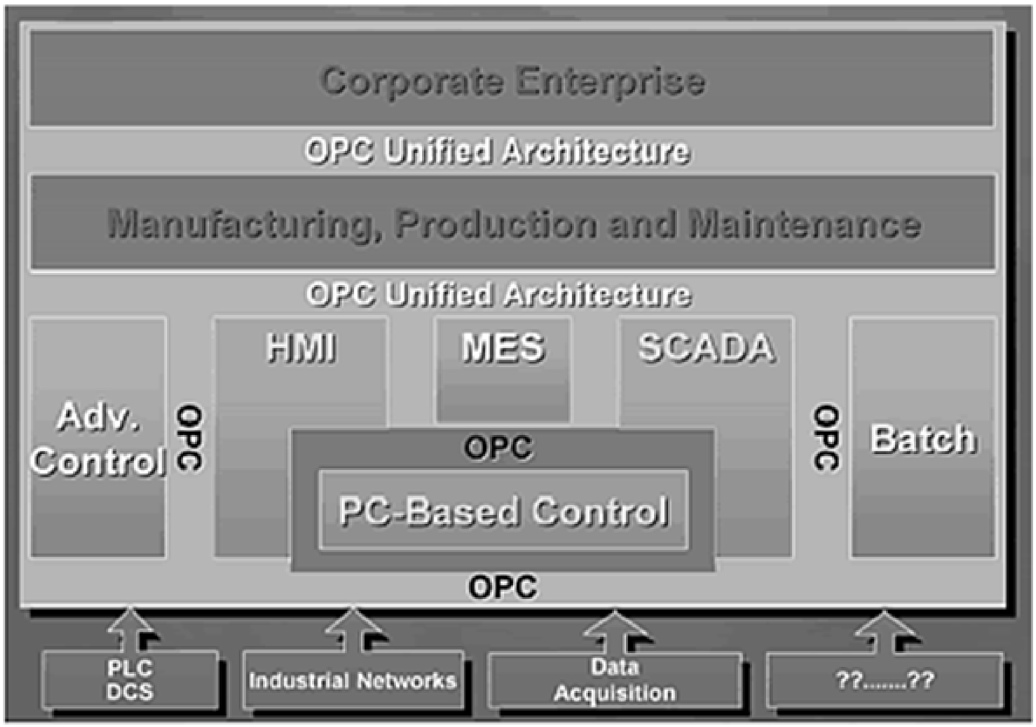

Figure 19. OPC UA operation range [91]

RFID

Alongside OPC UA, RFID is one of the corner stones for the Industrial Internet [87]. RFID, or radiofrequency identification, is a wireless Automatic Identification and Data Capture (AIDC) technology [92] that gathers data with special readers and attachable or embedded tags by the means of radio waves [93]. Those tags may be located at any physical object such as people, animals, documents or containers. Another advantage of the technology is the capability of RFID readers to interact with tags remotely and out of the line-of-sight [94].

Standards, that describe RFID technology at the international level, are of ISO/IEC origin. They form four main categories: proximity card (ISO/IEC 14443) and vicinity cards (ISO/IEC 15693), RFID air interface (ISO/IEC 18000), animal identification (ISO/IEC 11784, ISO 11785) and ISO supply chain standards (ISO/IEC 17358, ISO/IEC 17363-17367, ISO/IEC 17374.2) [98].

RFID systems consist of a RFID tag, a RFID reader and a backend IT system [95]. The systems are classified in accordance to the type of the tag used. It may be an active RFID tag with an inbuilt power source, a passive RFID tag powered by the signal of a reader or a chipless RFID tag sending its ID coded in its frequency response [96].

However, increased number of used RFID systems, with all their advantages and asset management improvements, has brought to life several challenges. Great number of tags and readers in a close environment lead to increased number of data collisions. These collisions fall into three groups: tag to tag collisions, reader to reader interference (RRI) and reader to tag interference (RTI) [97].

To achieve the goal of connected machines, a people and analytics, industrial Internet utilizes several advanced communication protocols. Namely, ZigBee, WirelessHART, CoAP, IPv6 and 6LoWPAN

IPv6 and 6LoWPAN

The number of devices connected to the Internet increases every day and widely used internet protocol IPv4 is no more capable of providing enough unique IP-addresses for every one of them. Due to the standard, IPv4 uses 32-bit addresses thus allowing 2^{32} (or approximately 4.3 billion addresses) [99]. This threshold and inconveniences, which it has created, has led to the design of the new version of the Internet protocol – IPv6. Address field of the IPv6 consists of 128 bits and provides a vital number of unique addresses (2^{128} or 3.4×10^{38}) [99] for comfortable operation of all upcoming IoT-enabled devices, smartphones and tablets to be used in Industrial Internet.

Industrial IoT-devices (like wireless sensors) are constrained in their computational capabilities as well as power consumption because of their relatively small size and the need for rationally long autonomous working time. Devices of this kind form a low power and lossy networks or Low-Rate Wireless Personal Area Networks (LR-WPAN) defined by the IEEE 802.15.4 standard [100]. By efforts of researchers those networks were enriched with IPv6 connectivity and now they are referred to as 6LoWPAN (IPv6 over Low-Power Wireless Personal Area Network or IPv6 over IEEE 802.15.4) [101].

In addition to 6LoWPAN, IEEE 802.15.4 standard serves as a foundation to ZigBee and WirelessHART technologies that gathering increasing credence as IoT providing technologies [102, 103].

ZigBee

ZeegBee is a standard based on IEEE 802.15.4 standard for wireless networks (WSN in particular). The ZigBee alliance is responsible for developing and promoting the technology [104].

ZigBee operates in the 2.4GHz frequency band globally or in the regional bands of 915MHz and 868MHz for Americas and Europe respectively and is able to operate over 16 channels at global frequency [105]. ZigBee possesses a versatile architecture [106]: the network layer of the standard support different network topology like star, tree or mesh. The network consists of a single ZigBee coordinator, multiple ZigBee routers and ZigBee End Devices (Figure 20).

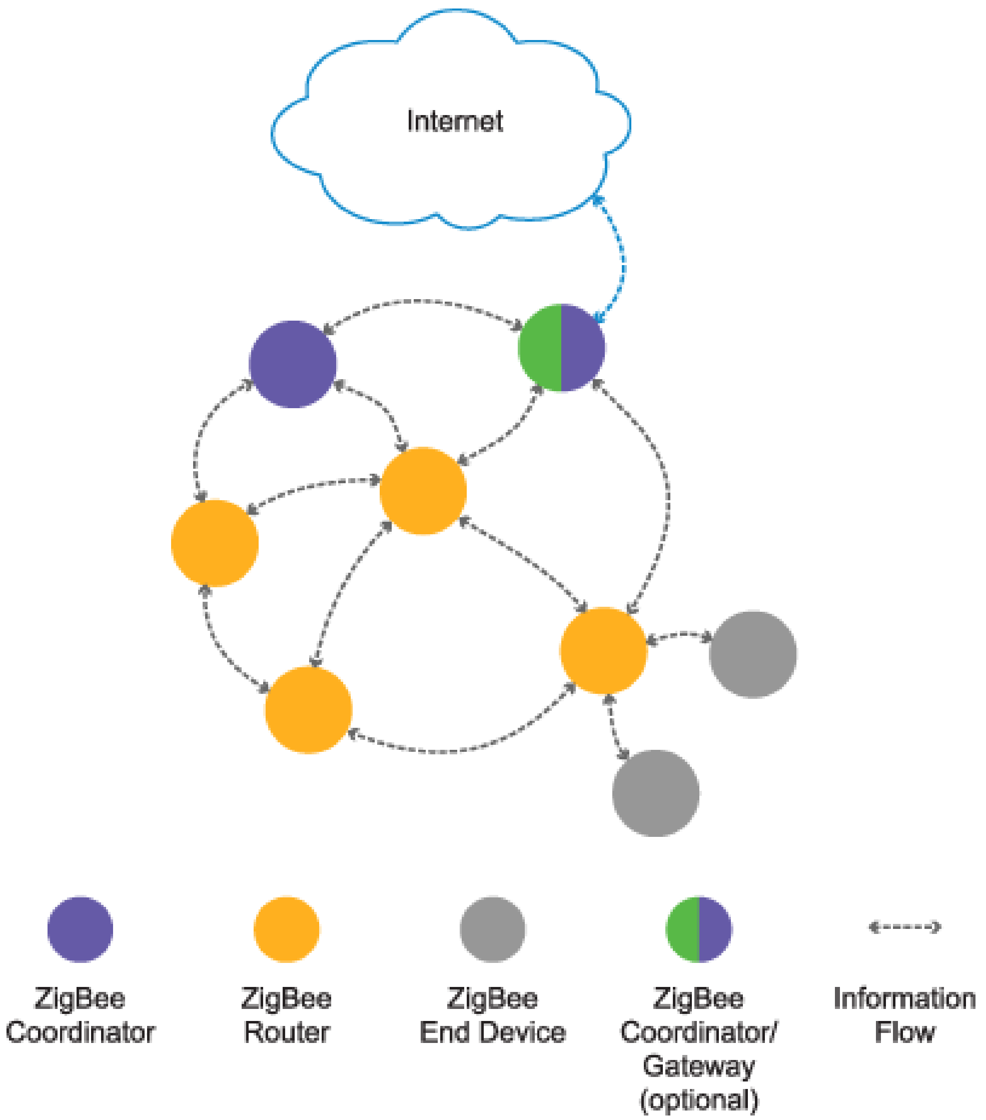

Figure 20. ZigBee network topology [105]

The protocol provides no quality-of-service (QoS) guaranties and may expose collisions at the low traffic due to use of carrier sense medium access (CSMA) [107]. Despite this and low data rate of 250 kbps ZigBee displays several advantages [108] like suitable communication distance between nodes, low energy consumption, cost effective network installation and maintenance, and high performance of data transmission. Table 4 presents comparison of ZigBee with other WSN technologies.

Table 4. Comparison of common WSNs [108]

Parameters	Bluetooth	UWB	Wi–Fi	ZigBee
Communication distance (m)	10	<10	50 – 100	50 – 500
Frequency range (GHz)	2.4	3.1 – 10.6	2.4 or 5	2.4
Data rate (Mbps)	1	100 – 500	11	250×10^3
Network capacity (nodes)	7	10 – 500	32	65536
Power consumption (mW)	1 – 100	30	500 – 1000	20 – 40
Complexity	High	Medium–high	High	Low

WirelessHART

WirelessHART is the first international standard that emphasized industrial wireless communication for process automation purposes [109]. It operates at IEEE 802.15.4 2.4GHz frequency and uses direct sequence spread spectrum (DSSS) and frequency hopping in attempt to reduce interference at physical level [110]. The standard support star and mesh topologies [111], and utilizes combined time- and frequency-division multiple access (TDMA and FDMA) [109]. WirelessHART network consists of field devices, adapters, handheld devices and gateways (Figure 21) [112]. The network exploit mechanisms for organization and healing of itself [109, 111].

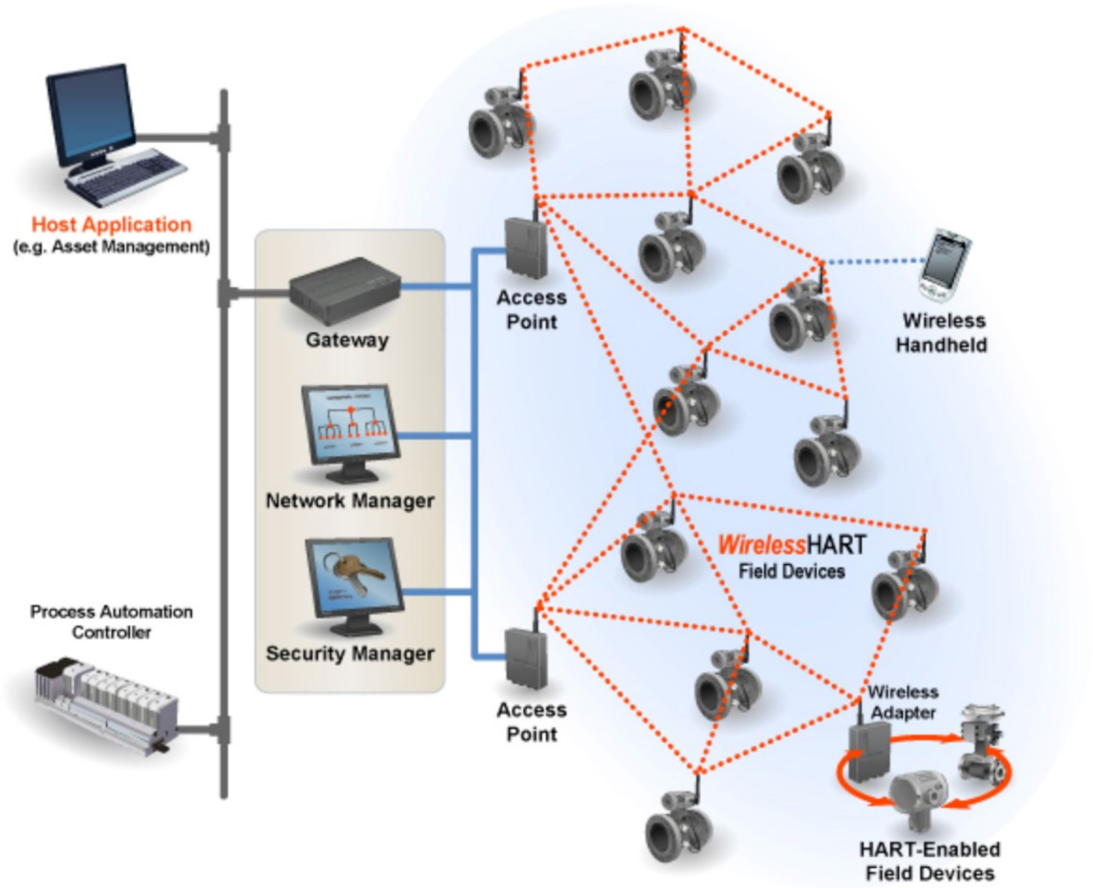

Figure 21. Industrial WirelessHART network [110]

CoAP

CoAP or Constrained Application Protocol is a web communication protocol, which was designed by the Constrained RESTful environments (CoRE) Working Group of The Internet Engineering Task Force (IETF) to provide resource constrained IoT devices access to Web services with a similar to HyperText Transfer Protocol (HTTP) approach, though maintaining interoperability with HTTP [113, 115]. Although, only IP-enabled objects may represent optimal utilization of the protocol [114].

The protocol applies a request/response interaction model and a publish/subscribe model, and uses the User Datagram Protocol (UDP) at transport layer with own mechanism for improving reliability on top of it to overcome UDP reliability issues [114]. Bundle of CoAP and UDP allows to minimize the amount of bytes exchanged up to 8-10 times compared to HTTP/TCP usage [115].

5. Industrial Internet Applications

Industrial Internet provides various benefits for different applications (Figure 22). Companies that adopted the Industrial Internet have shown remarkable improvements in their operation. Sections below describe some of the real-world implementation of the Industrial Internet concept.

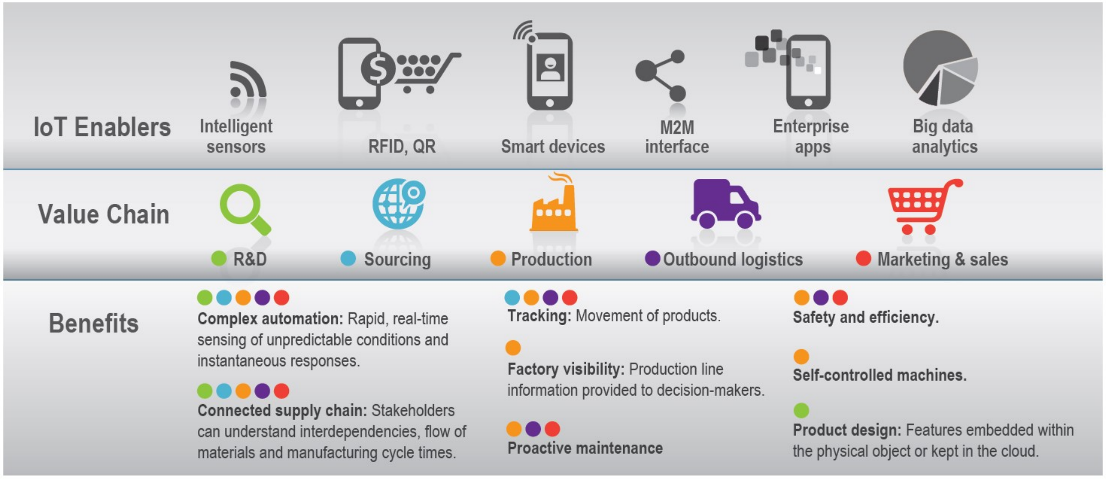

Figure 22. Applications and benefits of the Industrial Internet [116]

Case 1: Big Data Analytics for Predictive Maintenance

Nowadays, predictive maintenance (Figure 23) is the prevailing area for projects among all Industrial Internet solutions [130].

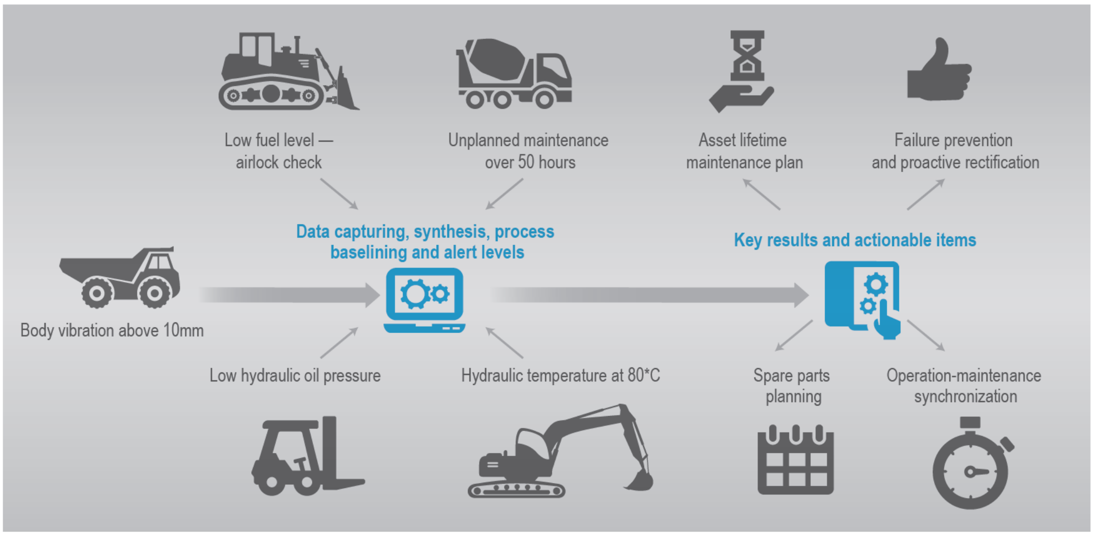

Figure 23. Predictive maintenance [116]

General Electric Company is one of the founding members of Industrial Internet Consortium [117]. It invests great amount of effort in collaboration with its partners to improve and spread Industrial Internet techniques. Recent cooperation with Shell, BP and Fluxys has shown significant achievements.

Royal Dutch Shell plc is a multinational company [118] and operates 38 offshore platforms being one of the top five companies by that number [119]. This implies an increased usage of underwater equipment that is hard to reach and needs to be monitored and maintained. Furthermore, possible malfunction may cause significant ecological consequences. To manage that challenge, Shell has tested Measurement and Control Subsea Condition Monitoring System by GE [120].

The company used its test pit in the Ormen Lange natural gas field, Norway, operated with a set of various subsea equipment [120]. The installed systems is the complex of acoustic sensors and carbon rods arrays covered with a protective dome [121]. Because of its shape, the whole system is often referred to as a 'birdcage' or simply the 'Cage' (Figure 24). The system is able to collect acoustic data in the almost 0.5 km radius (1600 ft) and to sense changes in magnetic field affected by electrical equipment. The configuration provides data collection without physical connection to the observed hardware [120]. Therefore, this creates an advantage of not affecting the operation of facility.

Figure 24. Measurement and Control Subsea Condition Monitoring System [120]

Proceeding the data allows to identify the type of a fault and to monitor operational characteristics of machines in use [120]. During the test project, the 'Cage' has identified and reported of several events in real-time, including the unexpected halt of different equipment operation due to causes of various origin, observation of unstable conditions and positive monitoring of machine characteristics [120]. Acoustic and magnetic field sensors provided additional information for faster and more accurate identification of fault reasons.

BP is an oil and gas company that operates numerous offshore facilities worldwide [121]. Their effective production process relies critically on vast number of rotating machines. Moreover, those facilities are usually located in hazardous environment that makes people transportation and presence there to be sometimes extremely dangerous. To cope with the situation, BP has brought into service System1 and SmartSignal software systems by GE [122].

As an outcome, key production sites around the world connect through a united network to the Advanced Collaborative Environment (ACE) centre in Aberdeen, Scotland. At the centre, BP monitors the data from various sensors equipped on offshore machines. Their operating status affects the amount of data collected with the finer processing of suspicious states [122]. Moreover, the system provides on-line expert support from globally spread dedicated remote monitoring centres [122].

Applied improvements have reduced monitoring personnel at the sites and improved its competence with expert assistance [122]. Thus, reducing the transportation cost. Another obtained advantage is a proactive maintenance based on Big Data analytics.

Fluxys is a natural gas transmission and storage system operator based in Belgium [123]. Their trouble-free operation is vital for the reliable performance of local industry. However, pipelines may be vulnerable to external impacts that might lead to severe damages. Because of that, it is crucial to observe real-time information on pipeline condition and integrity.

To achieve this goal, at the end of 2011 Fluxys has certified the ThreatScan system by GE through a European joint research project [124]. The next step was made in 2012, when in order to obtain the required data Fluxys has covered two 36”pipelines of 160 km with 39 sensors. Finally, in the beginning of 2013 the system reached operational state [124]. The system aims at the tracking and the recognition of damages made to pipeline by external action. These damages result in the change of acoustic environment that propagates within the pipe. GE Monitoring centre receives acoustic information from sensors, processes it, reports whether the damage occurs and were it is located [124]. If the system comes to a positive conclusion, the centre sends the notification of damage with full information about it to the company. This operational model increase safety and decrease downtime due to repair measurements.

Case 2: Safety improvements

The traditional way of safety alarms management is not very efficient. For example, when safety devices detect gas exposure, the alarm start to signalize and affected workers should leave the area and inform control room [126]. However, if the worker is disabled due to the injury control room supervisor stays unaware of the emergency as well as worker condition. Industrial Internet provides a new approach for safety monitoring at the plants of different industries. The one of available commercial solutions is the Accenture Life Safety Solution. It was designed by Accenture with incorporating technologies from Cisco, AeroScout and Industrial Scientific [125] for oil and gas, chemical, metals, mining and forest industries [126].

The idea of the solution is to transfer safety information from the worker in the field to the control room [127]. Every worker wears a multi-gas detector Ventis LS by Industrial Scientific (Figure 25) that detects hydrogen sulphide (H_2S), oxygen (O_2), lower explosive limit (LEL) hydrocarbon gases, carbon monoxide (CO), sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) [128]. The detector analyses the air from the 25 cm area of the breathing zone of a worker [126]. It is also equipped with panic button, motion sensor and Wi-Fi- RFID tag from AeroScout [125]. The tag sends safety information through the Cisco wireless infrastructure to the control room, where the location of the worker is also displayed [127].

Figure 25. A worker with the Ventis LS detector [127]

In case of the gas exposure, the detector will alarm the worker and will send information on hazard to the control room [126]. If the worker pressed the panic button or the device sees no motion of its owner, it sends additional information.

Control room personnel receives the real-time feedback on the location of workers, their physical condition and air content, and perform measures to deal with emergency [127].

Marathon Petroleum Company became interested in the system. In 2010, the company has tested the system at two units, and in 2011 decided to implement the solution at the refinery plant in Robinson, USA [129]. The refinery consists of around 20 processes on 1000 acres. In order to fulfill requirements of the company, wireless network was extended with mobile wireless access points mounted on trucks that use cellular connection to interact with central communications room [129]. Thus, Marathon Petroleum is able to monitor safety conditions and the status of workers at large open units.

Case 3: Remote asset monitoring

Another popular focus area is the remote asset monitoring (Figure 26). Modern Internet and communication technologies allows transferring high quality video signal with other sufficient information worldwide in close to real-time manner.

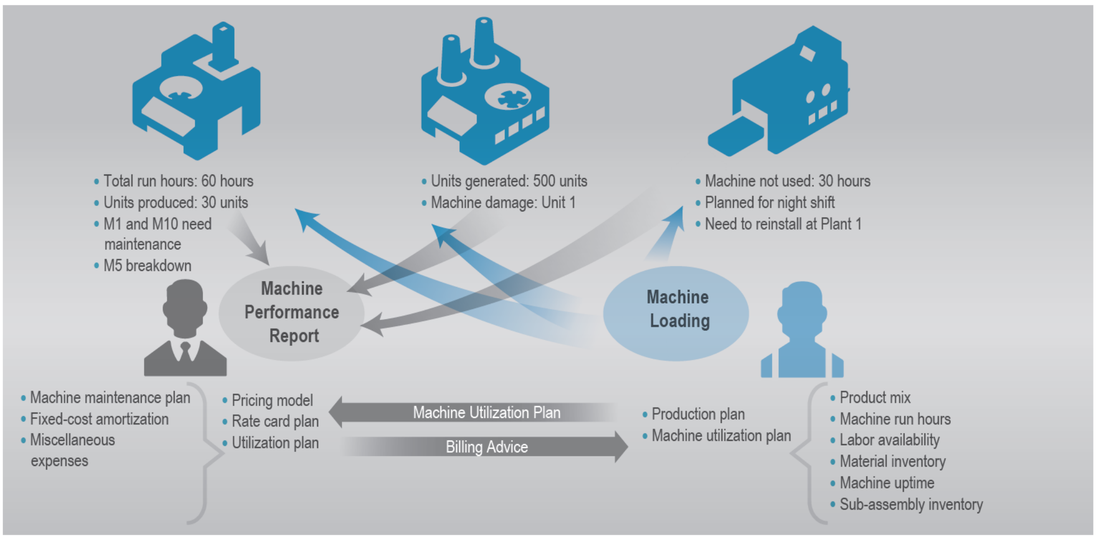

Figure 26. Remote asset monitoring [116]

Terra Ferma, the provider of portable communications, and Moxa, the manufacturer of automation solutions, cooperated to supply remote video surveillance and data acquisition system [131]. The system was designed for a company operating twenty wellheads dispersed over Rocky Mountains region in Central USA in a harsh environment [132, 133]. The challenge was to remotely monitor and control numerous sensors attached to every wellhead from a distant control centre [131].

Every wellhead was equipped with embedded computing platform, IP camera and industrial cellular router [133]. Additionally installed solar panels and wind turbines provide grid independent power source for the equipment of the wellhead. By the means of cellular network, all wellheads connect to the Control Centre and transmit all necessary information. At the centre, received telemetry and camera images during events are stored to the network server [133]. Figure 27 is a graphical representation of the system.

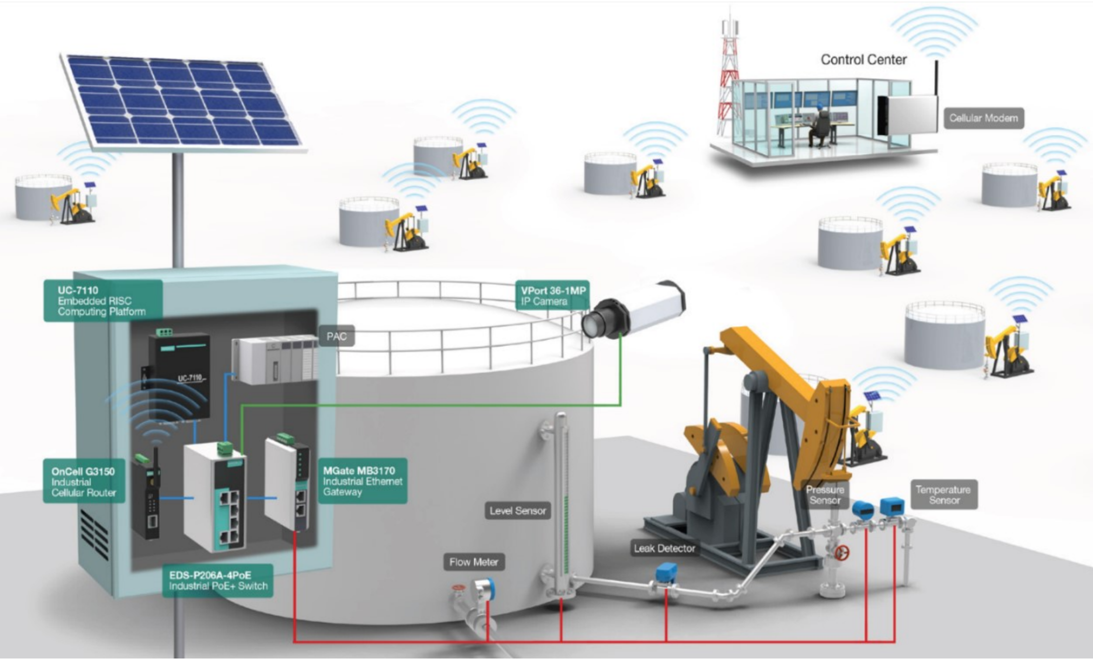

Figure 27. Remote Wellhead Surveillance and Data Acquisition system [133]

If a visual inspection is impossible due to severe weather conditions, the system will provide the maintenance team with real-time data and video signal to evaluate the operational condition of the asset [131]. At the occurrence of an event classified as a dangerous one, responsible technicians and managers receive a notification from the system. They may immediately observe information from sensors and the stream of IP camera from any device with the Internet access [133]. As a result, the system decreases the number of travels to the sites and mitigate the challenge for technicians, as they possess more information about the event at the arrival [132].

Case 4: Fleet management

In 2008, Rio Tinto, mining and metals company, has started a programme called Mine of the Future to advance mining technology and improve ecological and safety conditions at the mine site [134]. The company performs the programme at the Pilbara mine, Australia. The finished project should consist of five elements: remote operations centre, driverless trucks or autonomous haulage systems (AHS), automated drilling system (ADS), driverless trains or AutoHaul and airborne exploration drones [135]. Today, the first three components are already deployed and the AutoHaul system was expected to be deployed by the early 2015 [134].

Currently, Rio Tinto operates 53 autonomous trucks – the biggest fleet in the world [134, 137]. The company has plans to increase the total fleet to 150 trucks [138]. AHS trucks has moved 300 million tons of ore (Figure 28) since AHS deployment in 2012 [135, 136].

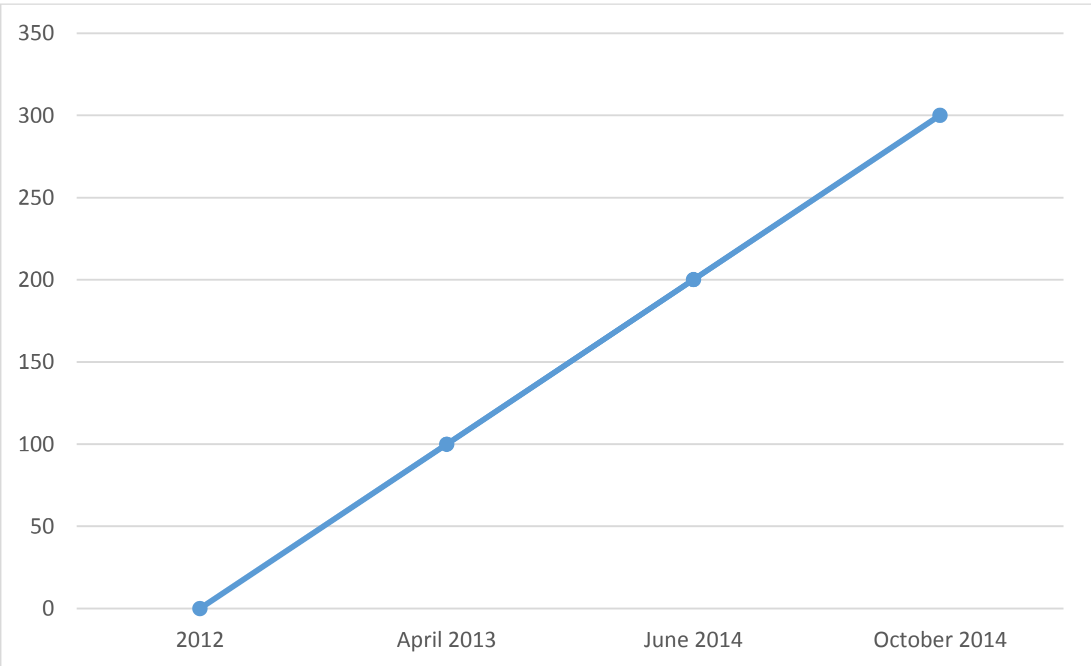

Figure 28. Ore moved by AHS trucks, mln tons, based on [135, 136]

Every truck is equipped with over 200 sensors (Figure 29), has a GPS receiver and a radar guidance system [139]. Operations centre in Perth, about two thousand kilometers away, controls the fleet. The routing of trucks is split into two sections: pre-set routes between the areas of the facility and dynamical navigation on roads and intersection [139]. Due to safety reasons, only the AHS connected vehicles allowed at the facility.

Figure 29. AHS truck sensors [139]

Also, the operations centre collects data from other equipment in the mine, workers in the field and geological instruments to the Mine Automation System. It represents this in graphical format, like 3D visualizations and predictive maintenance schedules [139]. The Mine of the Future, according to Rio Tinto, should have as least people exposed to hazardous environment and involved in repetitive task as possible [139].

Case 5: Complex Industrial Internet application

Several years back Dundee Precious Metals Inc. (DPM) in association with Sandvik, Cisco, AeroScout Industrial and Dassault Systèmes implemented several Industrial Internet techniques at its gold mine to decrease production costs and improve overall ore production.

Chelopech golden mine is located in Bulgaria and is owned by Dundee Precious Metals since 2003 [140]. The company has executed a $150 M worth two-year project (from the beginning of 2009 to December of 2011) aimed at ore production maximization up to 2 Mtpa by a new ore handling system and increased ventilation capacity [141]. Originally, the ore was transported by complicated underground transport system of trucks, wagons, rail tram, and hoist to a primary surface-level crushing facility. Present process consists of underground jaw crusher discharging to an ore bin that is connected to a surface stockpile with conveyor belt system of 4.2 km total length [142].

In 2009, falling metal prices has threatened Dundee's investments [143]. Therefore, in 2010 the company has started a new $10M initiative for the optimized management and resource utilization of the mine [148]. Those measures combined resulted in the decrease of the production cost of ore from US$59.38 in 2008 [144] to US$39.90 in 2014 [145] and ore production maximization (Figure 30). This result was obtained solely by optimizing the operation of the mine without any new mobile equipment being introduced [147].

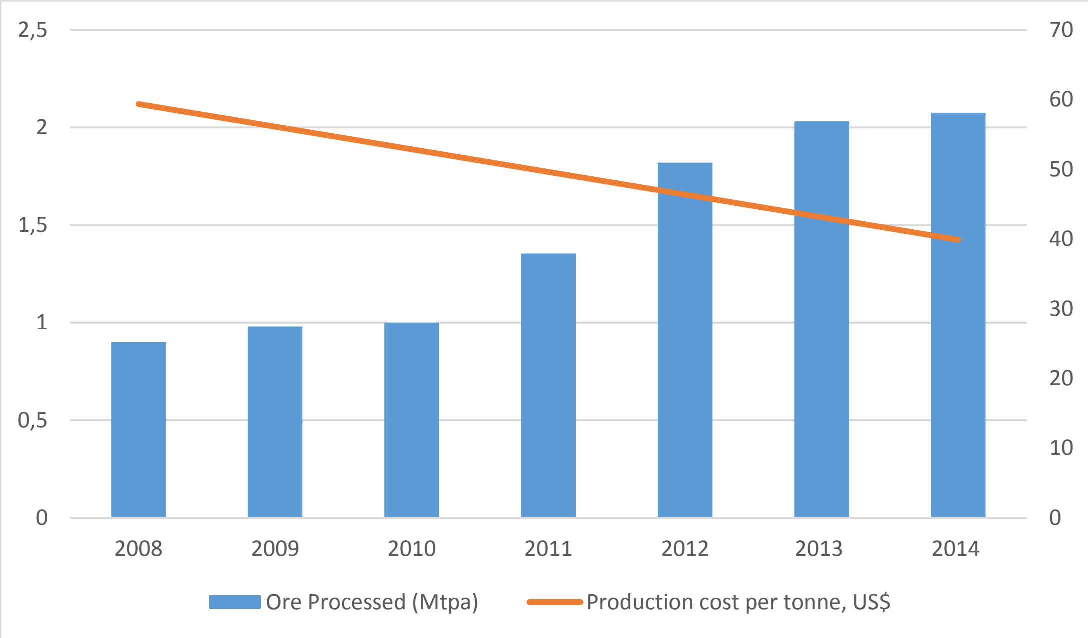

Figure 30. Ore processed and production cost at Chelopech mine, based on [144, 145, 146]

During this $10M project the company merged the Industrial Internet technologies with existing industrial and management processes. The main achievement of combined effort of operating company and solution providers was "taking the lid off". Rick Howes, CEO of Dundee Precious Metals, describes this solution as "real-time production management in an underground mine using … low-cost off-the-shelf Wi-Fi networks, inexpensive wireless RFID tagging for vehicle and personnel location tracking, and software systems for mapping, modeling, estimation, design, scheduling, simulation and mine production management reporting tools" [147].

The underground mine is a complex system that operates in shifts of up to 100 and more separate task per shift to perform. Those tasks should be assigned to workers and machinery and their execution should be monitored. However, real-time feedback on tasks and any kind of issues related to them becomes impossible due to the lack of sufficient communication opportunities underground. That situation constrains the ability of managers and supervisors to decide on effective action [148].

Unified Wireless network by Cisco provides reliable communication within 50 kilometers of the underground tunnels with 280 Wireless Access Points [149]. IT engineers has changed the shape of antennas due to particular geological properties of the mine [143]. Cisco also provided VoIP phones (later customized by the IT department of Dundee Precious Metals to offer push-to-talk (PTT) functionality [148]), instant messaging service and solutions for telepresence [149]. These technologies allowed to connect a person deep underground to one on the ground or even oversees with e-mails, phone and video calls, if there is a need [149]. It makes possible to receive real-time guidance by the manufacturer's technician in case of breakage of the equipment instead of asking him to arrive to the site [149], thus decreasing process downtime and expenses.

The underground network also connects vehicles, tablets, surveillance cameras and PLCs, blasting, ventilation, power and lightning systems [149]. Underground loaders and trucks are equipped with on-board system by Sandvik that monitors condition of the vehicle, tracks the load and working performance and reports warnings if they occur, so maintenance department is able to fix the equipment before it brakes down [148]. Moreover, task management software supplements this system with the corresponding tablet-based application. Connected life-support systems decrease the energy cost by adjusting lightning and ventilation based on the presence of people [149].

Wireless RFID tags are another important type of devices connected to the underground network. Over 1000 active AeroScout tags utilize the Wi-Fi network to transmit data and to define the current location by measuring the signal strength of the closest Wi-Fi access point [150]. Tags are embedded in the battery of the headlamp [151] to track people or placed in the cab of underground vehicles [148]. Complementary AeroScout software creates a map with all tags assigned to their location for better visualization and logs the history of movement [148]. Personnel tags also help to improve industrial safety during blasting - the blasting system will suspend the blasting signal if not workers has left the mine [149]. Despite of arising personal freedom concerns, Dundee Precious Metals states that it utilizes RFID tracking for optimization purposes only and not for surveilling the time spent on brakes [151].

All those technologies have created an opportunity for the use of the shift management software by Gemcom (nowadays GEOVIA) – part of the Central Monitoring and Control System (CMCS) [148]. This system receives a 7-day sift-by-shift schedule for the mine approved by all departments. The Central Monitoring and Control Room (CMCR) supervisor and the shift supervisor adjust the schedule at the shift change and then the shift supervisor assigns tasks for operators and equipment [148]. Tasks contain the information on the location, expected output and duration, and are spread through task management system mentioned above. The system provides the progress updates feature [148]. The shift management software logs all updates and present task execution progress to CMCR supervisor in a clear way, thus allowing improving performance by reallocating resources or taking other appropriate actions [148]. The CMCR supervisor uses that data for compiling of the summary report at the end of every shift and overall weekly reports.

After all, as Dundee has risked to become one of the early adopters of the Industrial Internet [143], invested efforts resulted in increased production, improved safety and asset utilization [149].

Summary

Despite the customization of examples reviewed in these cases made to meet the needs of the particular customer, they possess some similarity in the solved challenge and the applied solution. The similarity allows to unite them in generalized groups. Thus, Table 5 summarizes information on the Industrial Internet applications.

Table 5. Industrial Internet application summary

Application	Challenge	Solution	Outcome
Big Data	Processes generate vast amount of data that is too difficult to handle in traditional manner	Usage of special algorithms and methods of Big Data to process it	More data is available for analysis
Data analytics	The permanent need for modernization and optimization of the process	Utilization of data analytics tools and services available in the Cloud	New knowledge from the process data resulted in improved process performance
Predictive maintenance	Sudden breakage of the equipment introduces unacceptable delays	Big Data analytics of the information provided by (Wireless) Sensor Network	Decreased downtime due to planned maintenance of equipment before the incident
Safety	Workers often experience hazardous condition at the facility that is hard to monitor	In-door location system (e.g. based on active RFID), wearable detectors of dangerous medium, personal alarm buttons	Real-time acquiring of information on safety conditions of the facility and alarming of the personnel
Remote asset monitoring	Numerous quantity of geographically dispersed assets to be monitored and maintained	(Wireless) Sensor Networks, IP cameras, Internet connection, Central control room	Real-time data on asset condition, reduced amount and cost of personnel transportation

Table 5 continues

Fleet management	Workers, that are involved in repetitive task, tend to tire earlier and to reduce effectiveness	Substitution of people with the fleet of autonomous machines controlled from remote centre	Improved production rates due to continuous operation of the fleet, remote operators are more effective
Operation visualization	Lack of clear knowledge of facility operation between scheduled reports	Wireless Network covering the facility, Sensor Networks, portable communication devices for workers (tablets, VoIP phones, smartphones), in-door location system	Improved management decisions based on the clear view of the facility operation
Task management	Significant time of the reaction on changed circumstances because of need for assignment task in person	Advanced communications, location system, task management software	Real-time task assignment, control and progress monitoring. On-line feedback on task execution
Smart building	Building life-support systems operate invariably of changing conditions. That results in high heat and power expenses	(Wireless) Sensor Network, Smart building control system, location system	Ventilation, heat and power demands are fulfilled on demand. Decreased building operations cost.

PRACTICAL PART

6. Aim of the Practical part

The Industrial Internet is an inevitable evolutionary step in the industrial and business process automation and business optimization. Despite being relatively young technology, it has shown significant results in earning profit by production efficiency improvements or by operational cost reduction. However, only the minority of the industrial companies adopts the Industrial Internet techniques and solutions. According to [152] manufacturers in the USA are quite conservative and relatively suspicious about new technology with less than 14% of them having their machines connected to the enterprise network.

Recent technology development has paved the way for the wide adoption of the Industrial Internet. Mainly, due to miniaturization of computers and further price reduction for computational and communication powers. In spite of that, the latest technology leap has encountered several challenges, like lack of components standardization and massive data flows management.

Although, there is one more challenge, probably the main one, which stops companies from using the Industrial Internet of Things. The recent survey conducted by Gartner [153] has shown that companies struggle with the growth of IoT ecosystem, notwithstanding the high expectations of positive changes by the Industrial Internet, especially in manufacturing and retail. The barrier is the insufficient number of convincing new business cases.

As may be seen from cases above and collections of case studies, for example [154-159], through the last few years, the Industrial Internet has accumulated numerous case studies of its application to different industries: mining, logistics, metal, retail, cybersecurity and many more. However, the mineral processing industry experiences their shortage. This situation hinders mineral processing companies to achieve higher efficiency.

The aim of the practical part of the thesis is to design a convincing scenario for the Industrial Internet application and its usage for a metallurgical company operating a concentration plant. This part of the thesis consists of three chapters. The seventh chapter sets up the mineral processing plant under consideration and relationships with suppliers and customers. The eighth chapter provides the Industrial Internet application scenario description. The ninth chapter offers technical guidelines for the implementation of the system. The practical part, as well as the thesis is finished with the concluding section. There the future research directions are discussed.

7. Mineral Concentration Plant

The concentration plant operated by the metallurgical company follows rather traditional operating scheme. Main mineral processing operations (Figure 31) are performed in several particular circuits: crushing, grinding, separation and dewatering circuits [160]. The brief description of the circuits and involved unit operations is listed below.

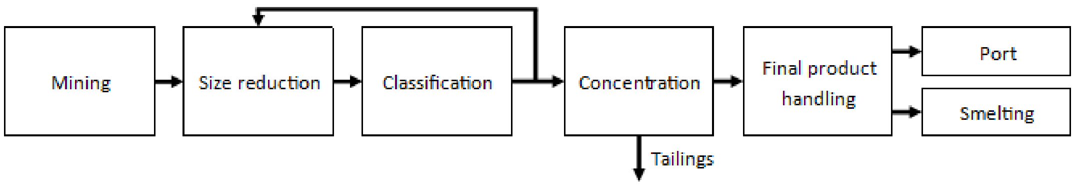

Figure 31. Mineral operations of the mineral processing plant [160]

Crushing circuit

The crushing circuit prepares the raw ore for further transportation and processing. It starts directly at the mine, where the blasted ore is crushed down to the size suitable for the next step. Located on surface, they receive that ore and minimize particle size to the desirable fineness. The resulted matter proceeds to grinding circuit at the plant.

Grinding circuits

To ease the extraction of the valuable components, the active surface area of the ore needs to be increased. To achieve that goal, crushed ore consequently passes to rod mill and a series of the ball mills (Figure 32). Hydrocyclones separate the outflow according to the size of the particles. A fine stream continues to the separation circuit and the coarse stream returns to the ball mill.

Figure 32. Metso grinding ball mill [162]

Separation circuits

To separate the valuable components of the ore, it is processed in flotation tanks. The fine stream from the hydrocyclone is mixed with required chemicals in a conditioner tank. Then, prepared slurry proceeds to the bank of interconnected flotation cells (Figure 33).

Figure 33. Outotec flotation cell bank [163]

It first passes the rougher separation circuit, the tailings of which are the feed stream for the scavenger separation circuit. Next, the tailings of this circuit feed the dewatering circuits and the concentrate is reprocessed.

Dewatering circuits

The excessive water content in the flotation tailings should be eliminated to obtain the output product of the concentrator plant. Use of the thickening process helps to achieve the goal. Flotation tailings mix with the flocculants in the thickeners (Figure 34) that simultaneously perform two tasks: recover water for the further usage at the plant and obtain the concentrate that is the mineral slurry with the increased content of solid particles.

Figure 34. Outotec Conventional Thickener [164]

The final concentrate is then stored and shipped to the refineries.

The DCS controls the operation of the concentration plant with PLCs responsible basic control circuits. Operator in the control room monitors the process with the help of HMI.

8. Industrial Internet application scenario for the concentration plant

The wide adoption of the Industrial Internet offers new prospects in improving overall performance to the implementing industrial company. Moreover, the Industrial Internet positively affects related companies in a multiplicative way. Thus, suppliers and customers working in close collaboration with the plant with adoption of required technologies may collect and exchange valuable information. Proposed application scenario is presented according to this idea.

Figure 35 illustrates the proposed Industrial Internet system for the concentration plant. CC, GC, SC and DC blocks in the plant block denote technological circuits of the plant. Thick lines show the material flow and thin lines show the flow of data. The description of the components of the system is presented below.

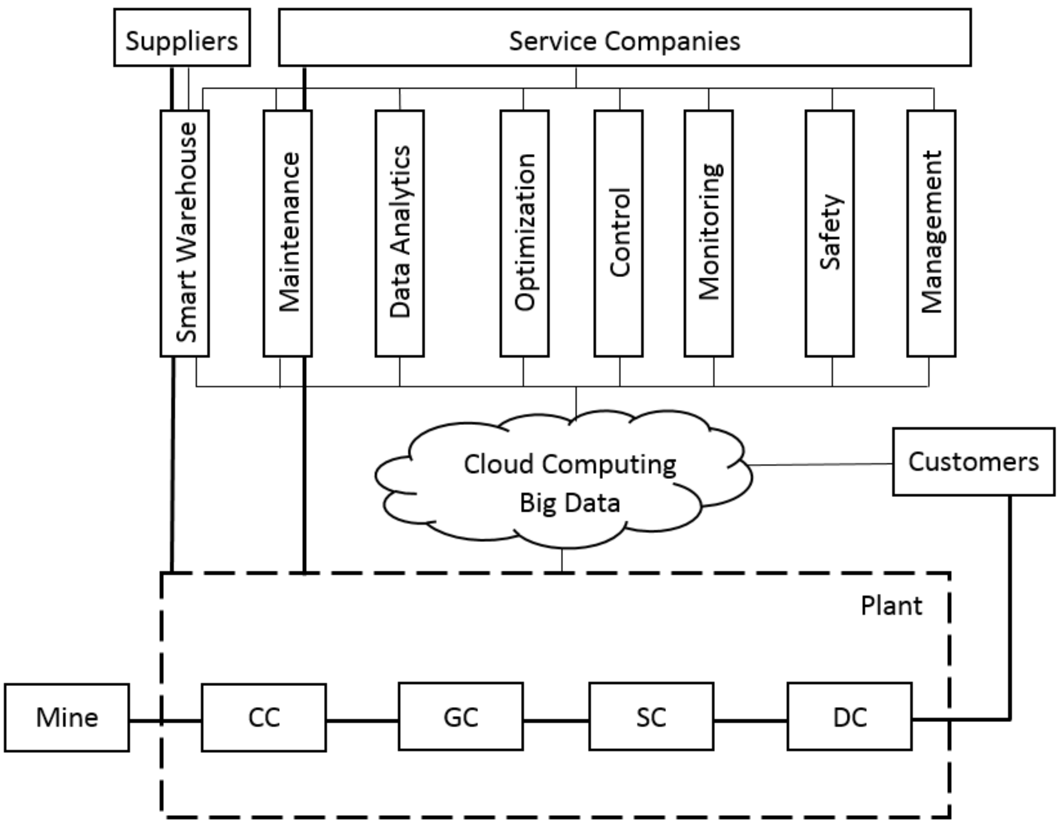

Figure 35. The Industrial Internet applications scenario

Cloud computing and Big Data

Cloud computing is the corner stone of the Industrial Internet paradigm of the process automation. The Cloud is used to store, exchange and process the vast amount of data collected from the plant and the customers and suppliers of the company. Traditional methods for handling the data fail to satisfactory perform with the data of that size.

To achieve the full potential of the Industrial Internet and Cloud computing new methods should be used. The area of the computer science named Big Data offers the set of effective techniques and algorithms to cope with the excessive amount of data. The utilization of these data processing methods allows to extract the new knowledge out of the data that is important for the next part of the Industrial Internet application scenario – data analysis.

Data analysis

That remarkable amount of information collected, ability to transfer it via the Internet and use powerful IaaS to process it provide the option of data analysis. This operation can be outsourced to the dedicated service companies and even to the producer of the equipment if such a service is available. They are able to supervise the condition of the equipment, technological and business processes, identify action patterns and provide the valuable notification and advice to the local technicians, managers and other stuff in charge.

This service is the basement for the majority of the Industrial Internet services. For example, it is intensively used in the optimization and predictive maintenance. However, it can be used as a stand-alone service, e.g., for the process analysis or process audit.

For instance, the performing of algorithms based on process data for the evaluation of the plant equipment physical condition may positively affect the overall operation of the plant. In [179] authors propose a method for detection of valve stiction of the paperboard machine. It is based on the characterization of the data sequences describing the process and control loops behaviour. Furthermore, different historian-based methods for the fault detection of analyzers like in [180] may be set up in the Cloud.

Another possible application is the analysis of the amount of solvent used during the flotation process according to the feed type, its physical and chemical properties. Acquainting this data and analysing it over a period of time, it is possible to estimate the consumption of the solvent and thus to place more expedient order for the next shipment.

Optimization

The main advantages of the Industrial Internet for the process application area are process optimization and process visualization. The first advantage relies on the recent developments in Big Data field of Computer Science. The latter one depends on higher speeds of mobile Internet connections and wider throughput of it.

The hundreds of variables that have different sampling time describe the operational process of the concentration plant. It requires significant computational powers and noticeable amount of valuable time to process this data and to result in applicable solution. The owning company of the concentration plant does not have required computational power. Thought it can and should rent the Cloud Computing powers through the IaaS services. Thus, the company should ensure continuous and secure data flow from the plant to the Cloud and the collection of sufficient data.

Convenient and instant access to the data should lead to closer and more productive relationships with universities and other research and process design groups. Granting access to the selected representatives of the research community during the ongoing project results in earlier start of the actual research. This loosing of bureaucratic barriers helps to create a model that is based on the latest process data.

Moreover, the company receives the advantage from this interaction too. The model can be verified and the process simulated with the real-time data at any time. The resulted graphical representation can be displayed simultaneously in the Cloud as well. Thus, the engineers of the company and managers in charge may observe the proceeding of the research and propose their comments, piece of advice and corrections immediately.

This kind of business-research collaboration could be illustrated with the integration of expert systems. For example, the expert systems presented in [176, 177] provide the valuable classification of the ore type and the useful guidance for its processing, as well as the sharing of the most effective treatment techniques among the operating stuff.

Despite of promising results, presented systems have several restrictions as a relative simplicity due to research purpose, on-site placement of the knowledge base and space and time distinction of off-line and on-line stages of the system creation and validation.

Moreover, the authors highlight the prototypic stage of the data transfer between automation and expert system. Thus, the additional maintenance capacity had arose. This has prevented the mine operators to continue the usage of the proposed system, notwithstanding visible positive economic outcomes.

The implementation of the expert system in the cloud allows to eliminate those constraints and even to improve the performance of the expert system. More powerful cloud computers may process more complex and hence more accurate models. Those models may be continuously updated, adjusted and validated with the fresh on-line data from the plant and close to real tome data from the on-site laboratory. Research groups and domain experts of the plant are able to communicate faster and with more convenient conditions through the cloud based services.

In addition, cloud-based expert system may provide wider and more versatile knowledge base because of higher storage capacities. This results in more accurate ore treatment. Furthermore, modern communication technologies ease the process of data gathering and transferring with almost no additional maintenance. More process variables are sent to the cloud processing with the higher throughput of the communication lines.

The operation of the updated system becomes more convenient and effective. Collected process data combined with the laboratory data is sent to the cloud and the industrial computer of the operator displays the computational outcome. As a result, the time of improper ore treatment is reduced and the overall effectiveness of the plant is increased.

Maintenance

The process in operation at the plant utilizes the remarkable quantity of rotating machines – crushers, mills, flotation cells, cyclones, motors of conveyor belts and other pumps and compressors. Conveyor belts and various pipes transport materials and products within the concentration plant.

The wide usage of the electric motors sequentially leads to the need of their condition monitoring and performing maintenance operation that is targeted at the prevention of emergency appearance and thus the technological process interruption.

Another aspect for equipment maintenance at the concentration plant is pipe transportation system. The significance of it rises with respect to the area of personnel safety. Pipes are widely used across the plant to transfer the final and intermediate products, technological and supplementary chemicals and other liquids like oil for the bearings of the machinery. Moreover, the pipes of the central heating system possess a potential danger to the workers in case of their damage.

Monitoring

Among other advantages of the cloud-based process applications there is implementation of different process monitoring techniques that require sufficient amount of process data for correct prediction and alarming. For example, authors of [178] propose a method for robust detection of persistent process oscillations that affects product quality. The utilization of Big Data and the CC allows the processing of the higher amount of industrial data and the more accurate notification of operating stuff. Moreover, due to improved computational power through the IaaS it is possible to implement more complex and more robust algorithm.

Furthermore, process-monitoring application may be used to basic transfer of the process trends and plant condition to the control and supervising room. The room may be located both dozens and thousands kilometres away from the plant. Additionally, a manager or an engineer with sufficient access rights is granted a permission to view this data. This may be helpful when one is at the business meeting in the other country or is on the different floor of the plant and requires information on the plant behaviour.

Control

Computational opportunities of the Industrial Internet able to perform better process control algorithms than conventional PLC or DCS. This will result in better product quality and reduced production costs. In [181] authors describe an actual control system for the lubrication system based on the SOA. The system was operated alongside the original PLC system and results were comparable.

However, the prototypic nature of the system has led to increased control cycle time. That was due to not fully optimized data transfer protocols and ineffective propagation of the data. As a result that has brought the system to the limit of stability. Despite that, with the improved algorithms and protocols of the finished system the difference in stability with the original system will be subtle, but clear in action.

Safety

The Industrial Internet allows decreasing the number of emergencies that are due to the intentional or unintentional violation of the safety rules. It also create an opportunity to prevent this kind of situations in future with the set of safety measures.

Safety measures combine the alarming of dangerous changes in the environment and the working conditions and the notification of entering potentially hazardous area of the plant. Furthermore, the safety system should allow a worker to warn the supervisor with an alarm signal about the health deterioration or unnoticed environment hazard.

This application also includes the tracking of the position of workers and mobile equipment at the premise to ensure that they would not be a cause or a victim of the emergency. The utilization of this system unites the safety application area with the management area.

Management

Real-time data provided via the Industrial Internet system combined with the actual position of the worker at the premises of the plant change the way workers of the plant are managed. The system assigns a task, evaluate its progress and report on completion. Additional comments from the head of the shift or responsible worker are possible.

Thus, it is possible to reduce the idle time of personnel and machinery, continuously update priorities of tasks and, hence, the number of involved workers and the time by which the task will be finished. Better utilization of the working force leads to the increased productiveness and overall profit. Especially, compared to the traditional form of per shift task management.

Smart Building

The energy and cost efficient operation of the plant is another component of the equipment area. That is, the rational utilization of the heat, light and air conditioning to maximize the potential of the workers and equipment and minimize the heat and electricity bills. The industrial internet solutions for Smart Buildings help to resolve the optimization problem.

Continuous on-line tracking of the people indoor location at the plant's premises combined with air conditions monitoring (like CO2 level, temperature, humidity) inside and outside buildings and information on the optimal operational conditions of the equipment results in the predictive alteration of the set points for the central heating system, air conditioning system and automated light system. Online nature of this building control allows merging the weather forecast and the knowledge of the behaviour patterns of workers with data from sensors for the better use of the environmental conditions.

Smart Warehouse

Updating the warehouse of the concentration plant to the Smart warehouse would improve the warehouse management, ease the ordering and minimize storing costs. This includes the storage both of chemicals used at the premise, spare parts for the equipment and expandable materials for the technological process like metal balls for the ball mill.

The system tracks the amount of stored items, predicts the future consumption and estimates the delivery time. Based on that, the system creates the most suitable ordering lists so to minimize the storage maintenance and logistics expenses and to provide the presence of the vital items. This ensures uninterrupted operation of the plant and reduced equipment maintenance downtime.

Customers

The system states a special approach to the customers of the plant. As the output product of the plant is not a mechanism or a final item, it is more challenging to offer them a product-related service that is one of the Industrial Internet cornerstones (see chapter 3.2 for more details). For instance, it is impossible to provide a maintenance service.

However, reimagining the value of the output concentrate as a product would lead to the new business strategy. According to this view, General Electric Company with its maintenance service for the plane engines does not sell the engines anymore, but sell the time of their faultless operation. Thus, I believe that the product of the plant could also be reimagined.

The new vision of the product originates in the benefits of the Industrial Internet system that it brings to the plant. With the optimized production, improved safety measures and smart storing of the spare parts and chemicals the owning company receives a better quality of the product, sustainable development and the production with minimized negative effect on the nature.

Hence, the company may sell not just the concentrate, but the continuous quality, participation in the sustainable development and ecological benefits. The customer may use this information as one of the marketing points for its final product.

Another advantage for customers cooperating with the company is the ability to visualize in real-time the movement of their order right from the mine to the exact train or ship on their way to the customer's warehouse. This helps the customer to better plan its own manufacturing.

9. Guidelines for the system implementation

The provision of the Industrial Internet operation at the plant requires the installation of the remarkable amount of wireless sensors and communication nodes. For their reliable operation, there is a need for plant-wide wireless network that will provide satisfactory signal quality at the areas of sensors and nodes installation.

This type of the network consists of server, network controller and access points. There are available ready-made solutions, the utilization of which represents to be the most convenient approach. Despite that, the IT department of the company may combine available industrial equipment from various vendors and install the wireless network. The department may use industrial wireless network components from, for instance, Siemens, Honeywell, Belden, Hirschmann, Moxa and many other companies.

Different companies, for example Cisco, manufacture ready-made systems for industrial wireless network. They offer Unified Wireless Network Architecture in the Enterprise (Figure 36) that may be adapted to the unique conditions of the company.

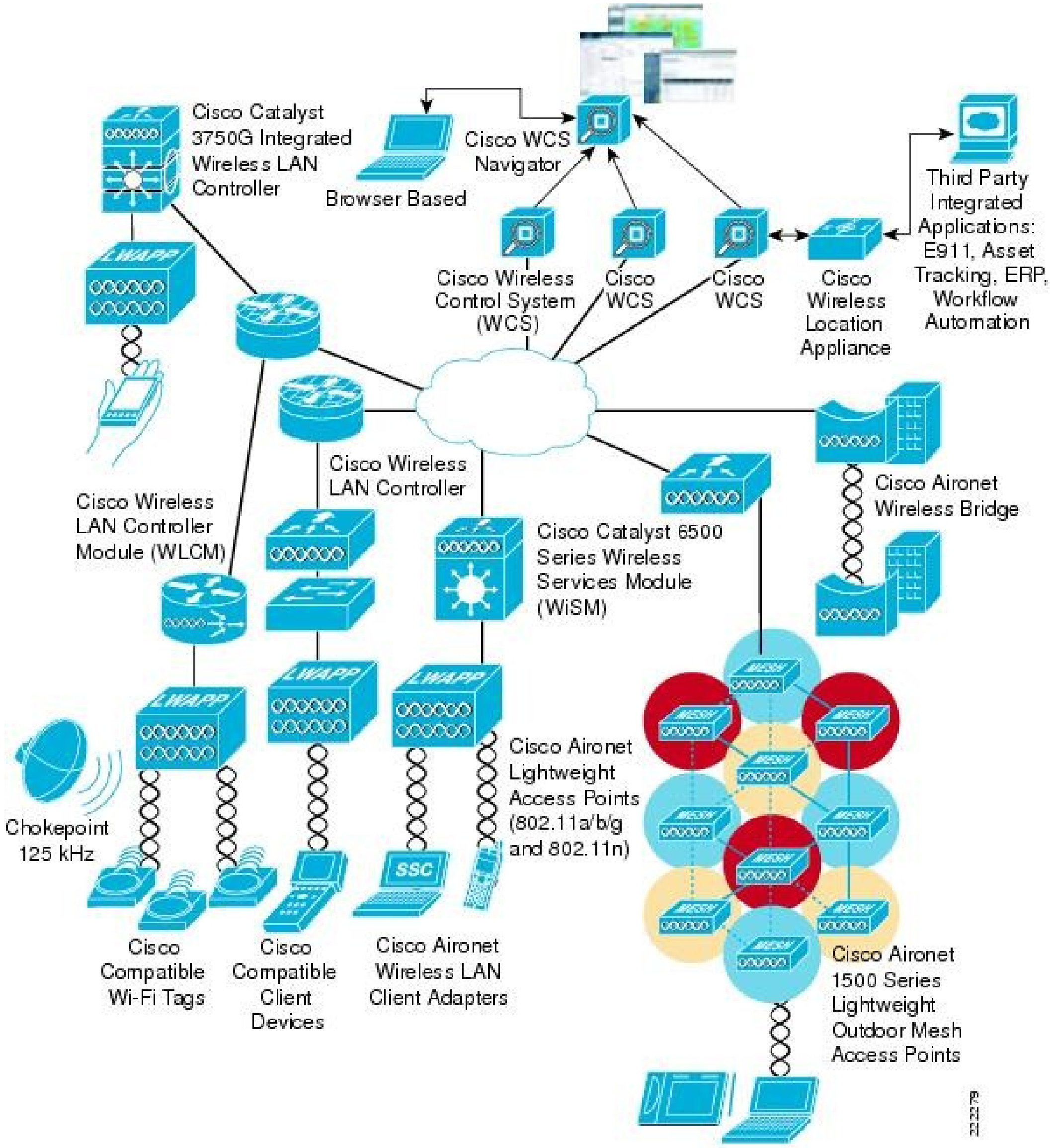

Figure 36. Cisco's Unified Wireless Network Architecture in the Enterprise [165]

The primary target for applying the Industrial Internet capabilities at the concentrator plant is the monitoring and predictive maintenance of the electric drives. First, there are ready-made solutions offered by the manufacturers of electric motors and drives. The motors they offer are combined with built-in sensors and controllers for better performance and condition data acquisition and better operation control with less additional instalments and less wirings.

Second, there are private solutions that may be implemented by technological department of the company. They are less versatile and mainly are represented by the instalment of wireless temperature and vibration sensors to the existing motors for better monitoring of the device conditions. Example illustration of the common sensor is given in Figure 37.

Figure 37. WiMon 100 wireless vibration sensor by ABB [166]

Various vendors offer their versions of the sensor at the modern market. Such companies as ABB, Banner, IMI Sensors, SKF and others are among those vendors. The sensors they produce are of similar characteristics that is clear from Table 6.

Table 6. Wireless sensors characteristics comparison [166-169]

		Echo® Wireless Vibration Sensor 670A01	SKF Wireless Machine Condition Sensor CMWA 8800	Sure Cross® Vibration and Temperature Sensor QM42VT1	ABB WiMon 100 wireless vibration sensor
Measured parameters		Vibration	Temperature Vibration	Temperature Vibration	Temperature Vibration
Temperature measurement range, °C		–	-40…+85	-40…+105	-40…+85
Vibration measurement	Velocity frequency range, Hz	4-2300	10-1000	10-1000	10-1000
	Velocity amplitude range, mm/s	0-101,6	0,2-350	0-65	±350
	Acceleration frequency range, Hz	2200-15000	500-10000	N/A	500-10000
	Acceleration amplitude range, m/s^2	0-196,2	0,25-245	N/A	N/A
Communications		Point-to-Point 900 MHz ISM Band to Echo Wireless Reciever	WirelessHART protocol IEEE 802.15.4 radio	3 meter cable with 5-pin M12 fitting to connect to the wireless node	WirelessHART protocol IEEE 802.15.4 radio
Transmission range		250 ft to >1 mile radius, installation dependent	50 m typically in plant	Depending on the node	>50m @ line-of-sight
IP class		IP 66	IP 66	IP 67	IP 66
Operating temperature, °C		-20…+70	-40…+85	-40…+85	-40…+85

Table 6 continues

Energy source	7,2V Li Battery Pack	Internal 3,6V Li-SOCl2 bobbin cell	3.6 to 5.5 V DC depending on the node	3.6V AA Li battery
Battery life	>5 years @ 3-measurements per day	Up to 5 years, depending on setting, usage and operating temperature	Depending on the node	>5 years with waveform upload interval > 1/day and vibration rms and temperature values upload interval > 1/hour
Weight, g	454	190	N/A	200

Another task is the integrity of the pipe system that should be continuously monitored and maintained. The aim is achieved with the exploiting the data from divers set of sensors. Acoustic sensors may be used to listen to the change of the sound along the pipe, temperature monitoring may detect the change in the thermal signature of the surroundings and gas analysers may track the traces of transported liquid in the air. Additional measures includes application of the electric field mapping (EFM) system. One of the producers of this kind of system is the Fox-Tek Canada, the subsidiary of Augusta Industries [170]. All those actions help to alarm responsible workers and supervision systems of any possible spills and leakages throughout the system of pipes.

Next area of interest is safety of the personnel. Conventionally a separate alarm button is used for rapid and convenient notification of supervising control room of any alarms or emergencies. The Industrial Internet system for safety supplements traditional technology with modern techniques.

The main component of the system is the indoor positioning system (IPS). The IPS provides real-time visualization of the actual indoor position of workers, vehicles, production units, sensors or actuators for the supervising system. This system is based on the utilization of the Wi-Fi, Bluetooth, RFID technologies and the data from auxiliary sensors both stand-alone and built in mobile devices (accelerometer, gyroscope, barometer, cellular data, etc.) [171, 172]. Hence, it may be implemented either as a separate system with dedicated equipment (like an active RFID location system in Dundee case study examined previously) or it may use corporate mobile devices, that is smartphones and tablets, to locate the personnel.

In addition to safety applications, the IPS is useful for plant navigation. That is convenient for new workers or for the workers of the service companies and helps experienced ones to arrive faster to their destination, for example, to rarely maintained actuator. Moreover, the IPS provides additional information on the location of the given task. Furthermore, it is possible to track the location of the worker during the task execution so that to assure that the assigned job is performed within safe area.

Both wearable and wireless fixed sensors and analysers supervise environmental conditions. Wireless sensors are the prior mean of the monitoring. They offer wider list of tracked characteristics compared to the wearable solutions, however they cannot equally monitor every part of the plant area. Thus, they are supported with the data from portable sensors. They are meant to be worn by the workers in the potentially hazardous production sites. This way they inform the safety system and personnel of the conditions of the environment directly surrounding people in concern. Usually, those portable analysers are equipped with the alarm button as illustrated in the case study listed above.

The task management challenge is relatively easy to find a solution. Nowadays, there are a sufficient number of the different task management software in the market. The company may choose the most appropriate version according to its needs. This software system, once installed, allows to assign a particular worker the individual set of tasks for a shift. Every task has a comprehensive description and a clear deadline. It provides a feedback capability so the worker may and should report on the progress of the task, notify when it is completed or when it cannot be completed on time with the reasoning and suggestions to solve the problem. In case of emergency situation or the idle period an additional task may be assigned. This system helps to effectively use the working time of people and machinery and to minimize the idle time.

Recent developments in the wearable electronics have offered a versatile tool to be utilized in the people area of the Industrial Internet application. It is a smart watch or a smart band with the built-in heart monitor. First of all, it is equipped with all communication technologies as its bigger counterparts – smartphones and tablets. Though it is a companion device, it may be used as a marker for the IPS, show notifications from the task manager and provide basic functionality to respond to them. Second, the heart monitor is accurate enough to distinguish the heart rate of the normal working state from the one of abnormal. This may be an increased heart rate due to the change in psychological (like fear or worry in case of emergency) or physiological (injury) state, or a decreased heart rate, for example, in case of lost consciousness. Any event should be reported to the supervising system so the responsible personnel can contact the worker and take the appropriate actions. Finally, the smart watch should be enhanced with software alarm button. It is not as reliable as the hardware one, however the operating conditions at the concentration plant should not damage the watch. Though, the traditional means of alarming should be preserved.

Another advantage of the smart watches is their multiplatform nature and the option to run the company software. This allows to embed them to the Industrial Internet system of the plant without much effort. The Table 7 present a comparison of smart watches features on different operation systems (OS). It shows that the company may achieve similar results without migrating from their current corporate mobile OS.

Table 7. Comparison of Smart watches [173-175]

	Apple Watch Sport	Moto 360 2nd generation	Samsung Gear S2 3G
Display	1.53”, 326 ppi	1.37” (35mm), 263ppi (360x325)	1.2”, 360x360 (302ppi)
Sensors	Heart rate sensor, Accelerometer, Gyroscope, Ambient Light	Accelerometer, Ambient Light Sensor, Gyroscope, Optical heart rate monitor	Accelerometer, Gyroscope, HRM, Barometer, Ambient light, GPS
Connectivity	Bluetooth 4.0, Wi-Fi 802.11 b/g/n	Bluetooth 4.0 Low Energy, Wi-Fi 802.11 b/g	BT4.1, WiFi, NFC
Battery	246 mAh – Up to 18 hours	300mAh - Up to 1.5 days of mixed use	300mAh
IP class	IPX7 water resistance	IP67	IP68
OS compatibility	iOS	Android, iOS	Android

Other devices to be used by the personnel to receive, report progress and comment on the tasks are ordinary tablet computers and smartphones or their rugged industrial versions. They are more convenient in use than the wearable electronics and provide wider options in processing the tasks.

The Industrial Internet paradigm only starts to collect credit from the industry and service providers. As an outcome, there are no available ready-to-apply solution to every challenge of the industrial and business sector. In addition, some production lines may be unique. Thus, the companies that want to be successful and to pioneer in the new technology application have to implement the Industrial Internet techniques on their own.

Fortunately, there are enough number of the IoT platforms. These include both software cloud platforms and hardware nodes. The nodes are based on microcomputers with built in wireless communication capabilities.

Many major software and industrial companies offer software platforms for the IoT and the II. For instance, Microsoft promotes Azure [182], GE advertises Predix [183] and SAP popularizes HANA [184]. Usually, operating company needs to create its own application or it may choose it from the list of already available ones. Conventionally, the platform offers specialized tools for application creation. They also support user-written applications.

Those platforms do not only allows building and deploying applications in the cloud. They also possess technical capabilities for device connection, machine and sensor data analysis. Also, the platforms are designed to easily integrate with on-premise enterprise systems.

A demo example of the system implementation with Azure platform is given in Figures 38 and 39. The monitoring and maintenance system display the status of the geographically dispersed premises, the KPIs of the production, alerts and warnings. Through the platform, this information is available to all authorised users across the globe.

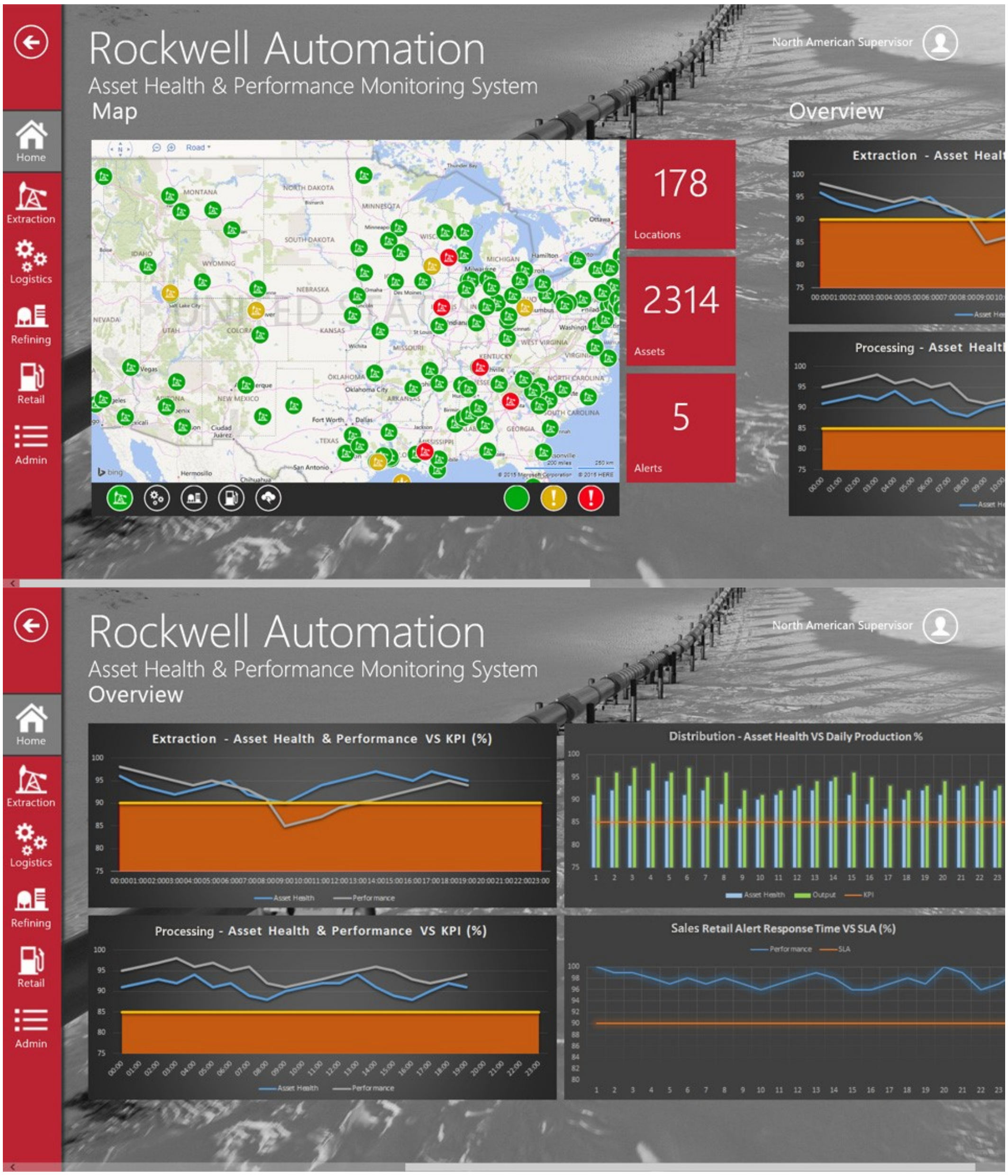

Figure 38. Microsoft Azure Demo IoT application, part 1 [188]

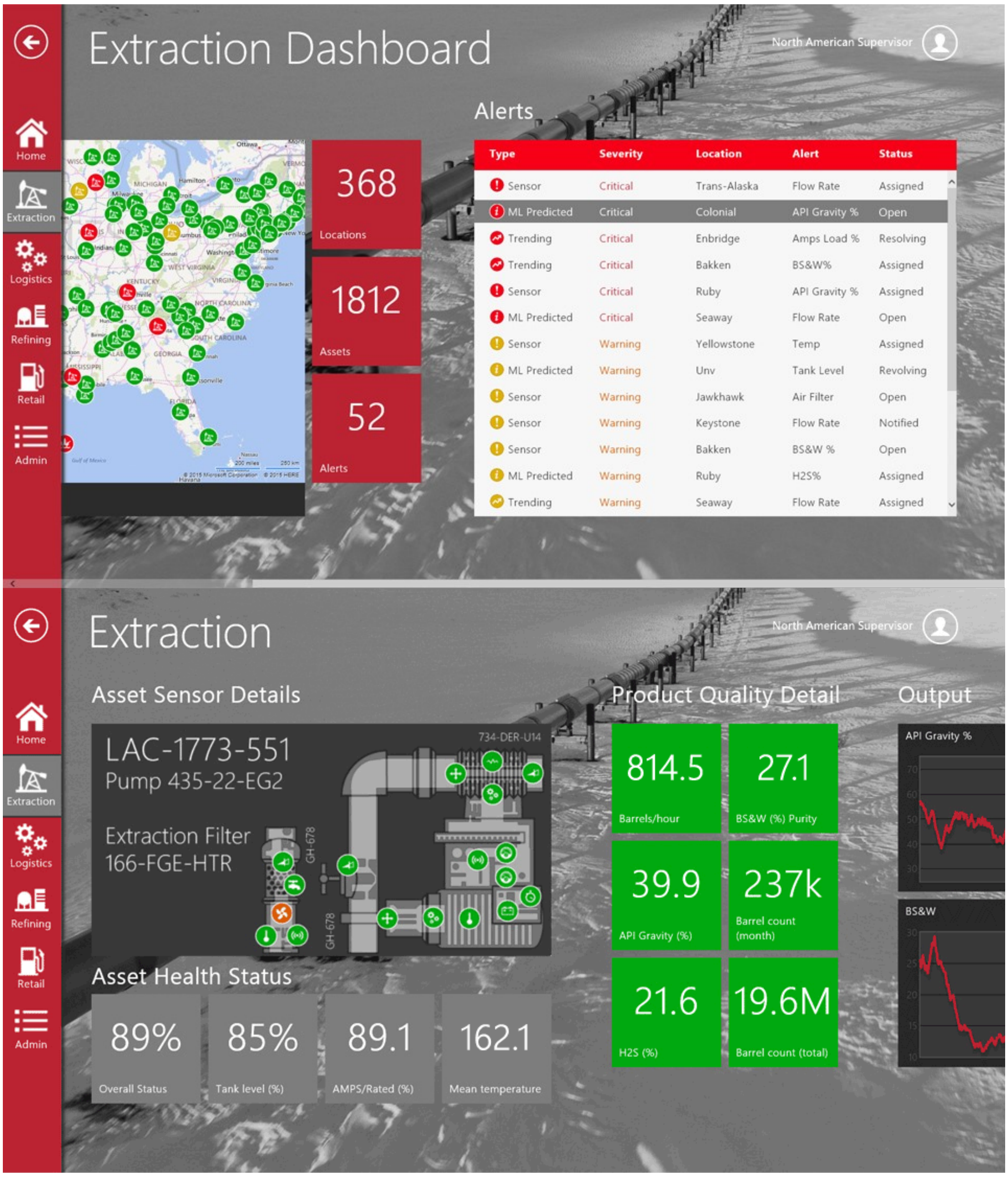

Figure 39. Microsoft Azure Demo IoT application, part 2 [188]

The hardware nodes are miniature computers with extended communication capabilities – Embedded Internet System (EIS). Example of their use may be seen in the [181]. In that case the Mulle platform (Figure 40) by Eistec.

Figure 40. The Mulle EIS

The main characteristic of such systems is their low power consumption that is crucial for the continuous wireless processing of data from multiple inputs and outputs and communications with the server. Notwithstanding their compact size (20.5mm*34mm for the Mulle platform above), these controllers are capable of processing several decades of I/O signals.

There are many other EIS on the market. Table 8 presents the comparison of some of them. The nodes listed in it are typical representatives of this kind of devices. They all run open operational systems and are based on common types of mobile processors.

Table 8. Comparison of the EIS[185-187]

	The Mulle Platform	Atmel Smart SAM L21	Black Swift
CPU	ARM Cortex-M4 100MHz	ARM Cortex-0+ up to 48 Mhz	Qualcomm Atheros AR9331, 400 MHz
Memory	512 KB program flash, 128 KB RAM	256 KB embedded flash, 40 KB SRAM	16 MB NOR flash, 64 MB RAM
Size, mm	20.5x34	33x36	25x35
Connectivity	microUSB, wireless IEEE 802.15.4		2×microUSB, 1×PLLD-1,27-30, 1×PLLD-1,27-20, Wi-Fi 802.11 b/g/n

Table 8 continues

Interfaces	4x UART, 2x SPI, 2x I2C, 2x CAN, 1x Ethernet RMII, 1x Secure Digital Host Controller interface, 1x USB On-the-Go with Device Charger Detection, 18x analog inputs, 1x analog output, 42x general purpose digital I/O pins	1xUSB 2.0, Up to six Serial Communication Interfaces (SERCOM) including one low-power SERCOM, each configurable to operate as either: • USART with full-duplex and single-wire half-duplex configuration • I^2C up to 3.4MHz • SPI • LIN slave	1×USB 2.0, 26×GPIO (general purpose input/outputs), 2×Fast Ethernet 10/100 Mbps, 1×SPI, 1×I^2C, 1×16550 UART
Power consumption	150 mA	35uA/MHz	60-300 mA
OS	Contiki, TinyOS	N/A	OpenWRT

10. Conclusion

The aim of my thesis is to create a scenario for the Industrial Internet application at the concentration plant. This scenario should explain the operating company, how they should use the Industrial Internet to maximize their benefits and improve overall production effectiveness.

In the literature review part outline of the modern state-of-art process automation is examined. Then various research and development projects of the Industrial Internet are described. These projects vary in their geographical origin and their views at the implementation, but are similar in their nature. After that, technological fundamentals of the new automation paradigm are presented. Those fundamentals include both hardware and software technologies. Standards and protocols are also important part of the Industrial Internet basis. Finally, the result of the Industrial Internet implementation is illustrated with several success stories from the companies that have modernized their businesses.

In the practical part, at first, the description of the mineral concentration plant under consideration is given. The main process circuits are listed. Then, the next section presents the Industrial Internet application scenario. The functional chart illustrates the scenario. Functions of the application are listed and described. Thorough attention is given to the relationships with customers and occurring challenges. In the following section technical guidelines for the system implementation are given. The section describes available hardware technology for implementing the Industrial Internet at the plant premises and the IoT platforms for execution of the software part of the scenario.

Based on the case study reports, scientific discussions and the positive results of process optimization and monitoring techniques, the scenario is believed to provide operating cost savings and improved profitability to all actors involved. Another advantages are better personnel safety, transparent task management and more clear understanding of the process.

However, at the moment the scenario possesses few disadvantages like high expenses due to the lack of standardized and relatively cheap equipment (e.g.

sensors) on the market. Another disadvantage is the need to design the system for every plant that also increase the expenses. Thus, I see the future direction of my research in designing a universal function block of the Industrial Internet system, that should be effortless to implement and that should be applicable to the variety of the industrial plants with the minimal changes.

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