TECHNICAL REPORT

Intelligent Industrial Processes - Big Data Devices

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ISSN 1402-1536
ISBN 978-91-7583-198-5 (pdf)

Luleå 2014

www.ltu.se

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Abstract

A versatile and competitive process industry is important for both Sweden's and Europe's future status as new players are emerging. To secure our position, constant improvement and development of industrial processes are required in order to increase productivity while reducing the pressures on the climate and the environment. One key area is ProcessIT (or Process industrial automation) in which several Swedish companies are world leaders in its development, delivery and application. The interest for new technologies such as Internet of Things (IoT), Cyber-physical Systems (CPS), Big data, and Cloud computing have been increasing rapidly the last years.
There have been a number of predictions from some of the world's largest companies in the business of computer communication, such as Cisco, Intel, Ericsson, etc. where the number of Internet-connected devices will reach somewhere between 30 and 50 billion devices by the year 2030. This will include traditional devices such as computers and laptops, tablets, smart phones as well as new types of devices such as resource-constrained sensor and actuator platforms.

Executive summary

Networked devices are belived to play a very important role on our future societies. The explosion of available devices, ranging from computers, tablets and smart phones to low-cost embedded systems, all with networking capabilities have drastically changed modern politics, business models and how citizens live their daily life. Inventions based on computer technology, such as the Internet, are already available for billions of users, and in a near future it is expected to somewhere between 20 and 50 billion devices will be connected to some network.

The core of this document is *Big data devices*, which is a novel term used to describe infrastructural aspects and challenges when deploying a very large number of (embedded) devices in application fields such as Internet of Things (IoT) and Cyber-physical Systems (CPS). If *Big data* is about efficient and scalabe processing of very large amount of collected data, then *Big data devices* is the field of collecting data using a large veriety of devices from different manufacturers using a plenthoora of more or less incompatible protocols. Big data devices captures the research, industrial and societal challenges when such a large number of devices are deployed. Key challenges include:

- Deployment and Configuration
- Scalability
- Security and access control
- Engineering
- Interoperability
- and others ...

The list above tries to capture most challenges that arise when a very large number of devices are designed to communicate with users, but also between themselves. Every device is most likely to have several simulantoues connections to back-end systems, databases, configuration and engineering tools as well as other devices. Each setting, such as to where a device should connect, where to get the security settings, where to send data, who is allowed to access the device, etc., must be maintained during the device's lifecycle.

Acknowledgement

The author would like to start with to acknowledge Prof. Jerker Delsing for giving me the opportunity to really investigate state of the art in this exciting research area. It is not often one can really spend this amount of time reading up on the research and development that is being performed around the world.
Discussions with Dr. Asad Khan and Dr. Amir Basirat at Clayton school of information technology, Monash university in Melbourne has contributed to drastically increasing the quality of the material in this report and providing useful input to the author.
Finally, the author would like to express gratitude to Wolfgang Birk, Fredrik Sandin and Evgeny Osipov for interesting discussions, suggestions and feedback when working on this white paper.

Contents

1 Introduction

A versatile and competitive industry is important for Sweden's and Europe's future status as new players are emerging. To secure our position, constant improvement and development of industrial processes are required in order to increase productivity while reducing the pressures on the climate and the environment. A key area is ProcessIT (or Process industrial automation) in which several Swedish companies are world leaders in its development, delivery and application. The area is very important in order to maintain and further develop a competitive national process industry. The area constitutes a global market with growth potential for SMEs through which they can grow by developing and commercializing innovations via corporate, university and divisional collaborations. LTU is leading in Sweden within the area of rendering more efficient basic industries and other industries using information and communication technology, so-called ProcessIT. To establish ourselves as a player on the European stage, we make use of our multidisciplinary strengths and the networks within which we have a leading position.

The interest for new technologies such as Internet of Things (IoT), Cyber-physical Systems (CPS), Big data, and Cloud computing have been increasing rapidly the last years. By combining sensor and actuator nodes, humans via smart phones and tables, and cloud services for data storage, visualization and control, a new breed of applications where humans can sense and control phenomena in the real physical world from the virtual world of computers and the Internet. This trend started with applications such as Dropbox, Amazon AWS, etc. where storage and computational elements

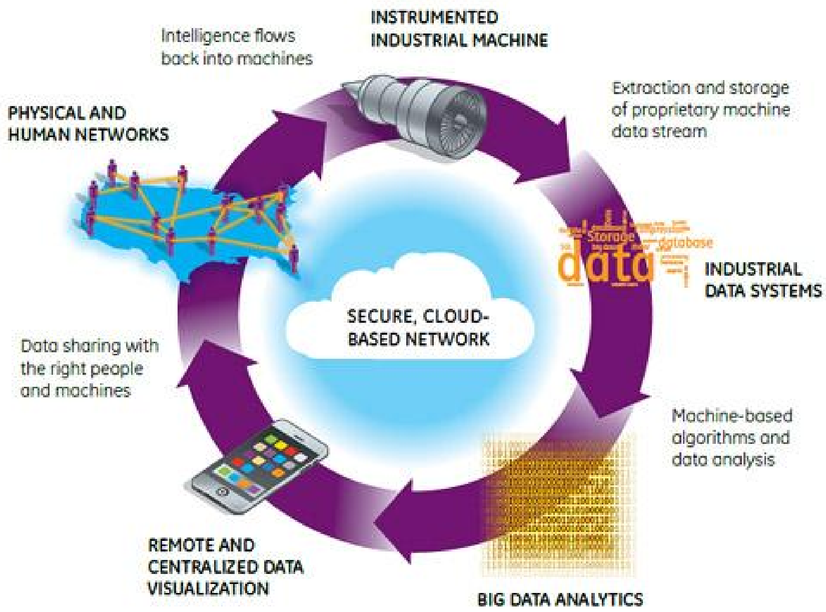

Figure 1: Internet of Things (source: General Electric Co.)

can be used to rapidly deploy resources when needed, and scale them up the the needs increase. We have just started to see this trend where emails, documents, pictures and other types of media is stored and accessed from cloud services instead of residing on a user's own computer. The first wave of applications focused on only virtual data (files, etc), but the rise of products and services in the field of IoT and CPS will shortly become a reality. When this type of technology reaches a larger market, users will be able to monitor and control an ever increasingly number of the own devices for entertainment, safely & security, home automation, e-health and my other types of applications. There have been a number of predictions from some of the world's largest companies in the business of computer communication, such as Cisco, Intel, Ericsson, etc. where the number of Internet-connected devices will reach somewhere between 30 and 50 billion devices by the year 2030. This will include traditional devices such as computers and laptops, tablets, smart phones as well as new types of devices such as resource-constrained sensor and actuator platforms. Today, a vast majority of of Internet-connected devices and computers and laptops, when a clear trend is that handheld devices such as tablets and smart phones, are now being sold at a greater volume than ever and will soon become the dominating class of devices. The amount of data currently being generated on the Internet is mainly streaming data, photos and videos where services such as Youtube, Facebook and Instagram and the birth of low-cost smart phones with high quality cameras has resulted in an explosion of data volumes. This is expected to already dominate over traditional data patterns such as web pages, e-mail and file transfers. When more and more devices such as smart phones, tables and computers but also house-hold applicancies become Internet-connected to a large extent, the data volume generated by billions of sensors for e.g. smart grids and home automation will start to become active the amount of IP-traffic generated annually is expected to exceed more than one zettabyte (one trillion gigabytes) each year after 2017 [1].

Computer paradigms such as Cloud computing with IAAS, is a hot research area, which together with Big data where massive amounts of data can be processed on large data centers is believed to be able to handle extremely large amounts of data. However, just the sheer number of devices will become a enormous challenge to handle since the number of interactions between these billions of devices can potentially reach a very large number of links if each device interacts with two to four services and other devices each. New methods for computer communication security, configuration, access control etc are needed to handle this massive amount of dependencies.

This report is outlined as follows: Section 1 contains this introduction and Section 2 presents the work metholodogy used in order to write this white paper. Sections 3 and 4 presents strategic agendas and a SWOT analysis. Suggestions for future partnersships and conclusions are presented in Sections 5 and 7, respectively.

2 Methodology

The work on this road map started in in the autumn of 2013, and has continued until late spring 2014. When working on this road map, the authors have tried to view the area without any consideration to personal interests, current research projects or similar influences. Instead, we tried to review the research area with an open mind, using a wide data set from national and international funding agencies, both the research and industrial community as well as political agendas. This white paper has been written in order to act as a complement to other white paper written within the IIP framework.
The following working methodology has been used:

1. Planning
2. Definitions
3. Investigation of strategic agendas, research councils, funding bodies, etc.
4. Harmonization with other IPP white papers
5. Summary and suggestions for future research directions, cooperations and identification of suitable funding bodies

2.1 Definitions

Since Big data devices in not a commonly used term, the authors have decided to put this term in context of other, more widely used, scientific terms.

Big data

Big data is usually used to describe processing of massive amounts of stored or streamed data, on the cloud, distributed systems etc. Data can be generated by humans (such as purchases, web data, search engines, etc), smart phones (pictures, sensors, positioning, etc.), as well as other sources, for example sensors, smart grids and similar. Today, several frameworks for Big data processing are available, both commercially (e.g. Google BigQuery), and as open source. Among the more popular open source tools are Hadoop from the Apache foundation.

Cloud computing

Cloud computing is a field of distributed computing, where programs, applications and services can be executed on several computers at the same time. Cloud computing enables sharing of resources and can increase dependability die to its distributed nature. Cloud computing is normally used as a computational platform for Big data processing. Google AppEngine and Amazon AWS are two commercial services where uses can purchase computational resources. Currently, there are several popular open-source solutions available, such as Eucalyptus, OpenStack and CloudStack.

Cyber-physical systems

Cyber-physical systems (CPS) has different meanings depending on who is using it. Traditionally, CPS is a term used to describe networked embedded systems which interact with the physical world for automation and automatic control purposes.

Internet of Things

Internet of Things (IoT) is the field of connected devices to the Internet using Internet-based protocols such as TCP/IP, DPWS, CoAP and similar protocols and technologies [4]. One strong driving force with IoT is to extend the virtual world of computers with the physical world of sensors and actuators. The main difference between IoT and CPS is that IoT is focused on IP-communication while CPS is focused on networked embedded systems and automatic control.

In [9], analytics company Gartner reported that they believe that that value added marked for Internet of Things will be in the range of almost two trillion US dollar, with some 30 billion connected devices.

Big data devices

In order to put the term Big data devices into context, we have seen that the previous definitions is mainly focused on sensing, communication and processing of (large) amount of data. Big data devices complements this by addressing management of thousands and even millions of specialized and often resource-constrained devices, such as embedded systems, Internet of Things/CPS devices, networked cameras, and similar.

2.2 Related reports

The IIP white papers outlined below are also a part of the overall work on SRT at LTU on investigation research directions and suitable partners for future research.

Intelligent industrial Processes - Automatic Control Perspective

In [2], W. Birk presented a white paper on current status and modern agendas from an automatic control perspective. The white paper also made some definitions what an Intelligent industrial process is, and made suggestions for future research directions. The outcome of this white paper was a proposal for research directions in the near future for LTU. The proposal included development of an Open Research and Innovation Platform, where both the industry and academia can collaborate by combining support for a virtual factory as well as a real factory, tools, data processing, etc.

Intelligent Industrial Processes & Enabling research challenges by Dependable Communication and Computation

In this IPP white paper [11], Osipov and Vyatkin presented state of the art in the field of computer communication with applications for industrial process monitoring and control. Osipov et al. concluded that more research are needed in the following areas: 1) cross-domain knowledge transfer,

2) globally connected industries, 3) support for flexible factories and processes, 4) IP security and user-centric IIP where even workers can be viewed as services.

Intelligent Industrial Processes & Enabling ICT - A Machine Learning and Intelligence Perspective

In [12], Sandin presented a white paper with focus on machine learning as an approach for industrial processes. By mimicking how problems are solved in the nature, so called bio-inspired solutions tries to adopt sensors and data processing used by simple organisms, such as bees, to the world of electrical engineering and computer science.

Intelligent Industrial Processes &A roadmap for big-data research and education

In [13], a roadmap for research in Big data, data centers, and similar fields were presented. The focus in this report is on more traditional cloud computing technologies within Big data. The main difference with the white paper on Big data devices is that the Big data devices is focused on technologies underneath data centers, i.e. large scale deployments of (resource-constrained) embedded devices such as sensor and actuator platforms, gateways, protocol interoperability etc. To conclude: if *Big data* is the area of cloud computing and parallel processing of massive amounts of data at data centers, then *Big data devices* is the area of managing the very large number of devices needed of feed the data centers with.

3 Strategic agendas and objectives

This section presents strategic agendas in an international context. Several white papers from strong international funding agencies, research councils etc. have been compiled and evaluated. The authors of the white paper have tried their best to review these agendas objectively, without concern of current or planned research at Luleå University of Technology.

Covering the the world's strategic agendas is of course a futile task, and below is a selected number of research agendas from what was deemed the most suitable and relevant organizations.

3.1 EU and Artemis

In [7], a report from a workshop on the impact of Cyber-physical systems and the impact on European economy is presented. Currently, European companies has a 30% of the world market for embedded systems, and staying at the technology forefront is one of EU's long term goals. Substantial research funding will be made available for research within embedded domain, process monitoring, e-Health, etc within the Horizon 2020 framework. In [3], Artemis' road map for the Horizon 2020 framework is presented.

3.2 The IoT European Research Cluster and European Research Cluster on the Internet of Things (IERC)

The IoT European Research Cluster and European Research Cluster on the Internet of Things (IERC) has released number of white papers and strategic agendas (see for example [15], [14], [10]).

3.3 European Roadmap for Industrial Process Automation (ProcessIT.EU)

In [8], a roadmap targeted both industry and academia from ProcessIT.eu is presented. ProcessIT.eu is a center of excellence within Artemis and has close collaboration with the Swedish and European process industry, mainly within paper & pulp and mining.

3.4 The Future of Cloud Computing

In [10], the European Commission, Expert group reported that cloud computing will be an important key technology for developing new products and business in the next decade. Recommendations are that the European Commission should support research and development in fields such as; standards, large-scale test beds and open source solutions.

4 SWOT analysis

This section presents an initial SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis. Further discussion is required before the analysis can be used and presented in a roadmap. The SWOT analysis can be seen in Fig. 2.

Figure 2: SWOT analysis

4.1 Strengths

In the strengths category, it can be concluded that LTU has a very strong industrial connection and is well-knowned within the process monitoring and control field with European companies such as ABB and Schneider Electric. LTU has also a good reputation with funding agencies, both national and international. Researchers from LTU has also a good track record from participation in European research projects.

4.2 Weaknesses

One weakness is the location of Luleå, far from the heart of Europe. This makes it difficult to be visible in the press, bit also to attract students to some extent. Since there are not many large enterprises in the vicinity of Luleå, LTU is highly dependant on being visible and making companies and funding agencies aware or our presence and capabilities. LTU is also highly dependant on external funding since national basic research grants from e.g. Vetenskapsrådet are low.

4.3 Opportunities

The current trends within the academic and industrial communities has given LTU a strong position. The Arrowhead project for example is a good indicator that major European agencies see LTU as a high quality university. By delivering research of high quality and increasing he number of publication on top ranked journals and participation at international conferences, LTU can continue to be known as a high quality university. By attracting post docs and an increased cooperation with other universities within Europe and the rest of the world, we can continue to attract attention from media, politicians, enterprises as well as the society.

LTU has also been a strong force within the Internet of Things world, even though we have in generally been poor in attracting attention. By actively participating at fares and conferences, and contributing to standardization bodies we can make an even larger impact.

4.4 Threats

One of the biggest concerns currently is being able to recruit PhD students of high capabilities. The distance from the rest of Europe and general trend in the west that students to a high level view engineers as a 'boring' profession makes it difficult to attract PhD student. LTU also usually has a lower level of acceptance compared to other top universities in Sweden. The lack of basic research funding also makes in very important to spend considerable efforts of writing funding applications, working on cooperation with the industry and similar activities. Statistics also show that LTU is also more sensitive to variations in the availability of the number of 18-20 year olds in Sweden than other universities, much because of the location near the arctic circle.

5 Stepping stones and partnerships

This section will present a suggestion for action to perform up until 2030, and will try to identify strategic partners to either strengthen existing cooperation with in initiate new contacts.

5.1 Stepping stones towards 2030

Below is a road map presented with activities and aims for the next 15 years. The foremost aim is to establish LTU as an European Center of Excellence in the field of industrial intelligent processes, with strong connections to automatic control, computer communication and security, Internet of Things/Cyber-physical systems, as well as Cloud computing and Big data.

2015

Initial collaboration efforts with identified strategic partners and long-term planning. Work on strengthen LTU and ProcessIT.eu with visibility, road maps, publications, application, media, etc.

Better integration between undergraduate education primarily with the Computer science and Engineering physics and Electrical engineering Masters' programmes with the goal of easier attracting PhD students and preparing LTU's students for future European challenges in automation, process monitoring, CPS, etc. Preparation of Master's theses, project courses is also important.

2020

First initial implementation of framework for simulation and management of large-scale (sensor) networks supporting the visions in [2]. Major impact with high-quality publications and industrial awareness of progress. PhD students examined in this area. LTU is also actively contributing to international standardization organizations such as IPSO Alliance, W3C, and IETF with standards, protocols and review.

2025

Partial framework with SOA-support, full integration with simulation environments, and basic deployment and life-cycle management as well as security mechanisms. the framework is prepared for deployment on cloud engines such as AWS, Eucalyptus, OpenNebula, and others.

2030

Integrated framework with SOA-support, integrated simulation, deployment and life-cycle management as well as security mechanisms. Framework is fully integrated with cloud engines for fault-safe and high performance computing.

5.2 Partnerships

Below is a preliminary list of identified suitable partners for this white paper. This list must be updated on a regular bases to better capture future needs and collaborations. Activities such as joint publication, PhD defense opponents etc. could be used to initiate a collaboration.

Swedish Institute of Computer Science

SICS have been holding a strong position within the IoT and networked embedded systems domains, and having a close collaboration with them would increase LTU's visibility.

Monash University

As ranked among the world's top 1% universities and an already ongoing collaboration, Monash University in Melbourne, Australia is a natural future strategic partner. Already working with Big data, Internet of Things, and Bio-inspired computing, deepening the current collaboration would be beneficial.

University of Bremen

With research groups in area such as Artificial Intelligence, Cognitive Neuroinformatics and Computer Architecture & Reliable Embedded Systems, University of Bremen makes a good match with LTU's research areas.

ETH Zurich

The Distributed Systems group at the Department of Computer Science and Pervasive Computing at ETZ Zurich has produced some very interesting results the last years. This group works for example with CoAP, IoT, and distributed systems.

6 Research directions

This section presents suggestions for future research directions suitable for SRT and LTU to address. This list is not a final recommendation, but is subject the change.

6.1 Cloud integration

Future architectures for data storage, configuration, visualization and similar features are very likely to be cloud based. By utilizing elastic clouds, where memory, storage and processing power can be dynamically allocated provides a very attractive solution. However, since this type of architectures are often very generic they suffer from being suitable for integration with resource-constrained devices. Research issues such as multi-protocol systems, systems-of-systems and SOA can be found in this category.

6.2 Engineering tools & Automatic control

For the future European industry to have an competitive edge, it is vital that the production of material, products and energy can be done in a cost-effective and environmentally friendly manner. Several research fields have been identified that will ensure that Europe's companies can rapidly adjust to changing market needs and requirements, and easily adopt to future standards and regulations.

Virtual nodes for the virtual factory of the future

By having a virtual model or representation of a plant or factory, large gains in terms of automatic control are feasible. By running a process in an optimal way reduce waste, minimal energy consumption and thus keep costs down. This is vital if Europe is to be able to compete with for example the BRIC countries.

In [2], Birk suggested that an open platform for simulation, control and optimization could be used as a tool for integrating simulated and real data, between the industry and well as academy. However, since a modern platform can have hundreds of thousand measurement point making a virtual factory is not a trivial task. The virtualized devices must be able to fully capture all dynamic properties and interactions between each other all all other involved systems in the plant. Functionality must be able to be moved between real devices and virtual devices transparently in the tool if new features or optimizations are to be transferred from the R&D domain to production.

Seamless engineering tool integration

Engineering tools are becoming more dynamic, as operators can use hand-held devices such as laptops, tables and smart phones to access sensors, actuators and systems on the factory floor. This also puts requirements on the infrastructure for devices, services and systems to be discoverable and accessed. Engineering tools for process monitoring, control, maintenance, etc, must be able to communicate using a possibly wide variety of communication protocols. Devices must therefore be able to announce their presence and capabilities without breaking backwards compatibility with legacy systems and also to be able to be upgraded with new and improved functionality.

For a device to be useable through its life cycle, it must be able to interact and share information about supported protocols, semantics, current software version, faults etc.

Usability aspects

Modern and future smart sensors are becoming more and more complex. State-of-the-art devices today support for example secure IP-based communication and a multitude of protocols such as OPC-UA, Modbus, Profibus and others. However, since more and more software functions are added to a device, the more it becomes vulnerable for software errors, viruses and erroneous usage. There is also a trade-off between usability and security, i.e. staff might not enable security features simply because they are to time-consuming and complex to use. When more and more devices are starting to be used, they must also support self-diagnostics and self-tests, meta data about their position, and what they can measure and/or control.

6.3 Elastic Service Provisioning

Elastic computing refers to technologies for dynamic provisioning of required resources in terms of computational power and storage. The term is normally used for describing how cloud-based clusters operate, i.e. server resources are automatically allocated and provisioned when a customer's demands changes over time. For example, a small company can start with one or a few servers to host web pages, databases, and other CPU-intensive services. As the company's products become popular, the cloud can dynamically add and remove more resources at an optimal cost.

With Elastic Service Provisioning, we mean that services can not only be dynamically allocated on servers in a data center, but rather deployed where they are most needed for sensor networks. For example, a gateway might run some CPU-intensive service of type X, but when the available resources are not sufficient the X service can be seamlessly transferred to a cloud-based resource and continue executing there. This approach would allow for the use of mixed types of devices, ranging from resource-constrained sensor and actuator platforms to gateways, middleware and cloud-based services. By dynamically adjusting for changing requirements, trade-offs between power-consumption, latency, availability and other parameters can be achieved.

When using Elastic computing, it is all about starting up an identical copy of some software or service on another virtual or physical server within a data center. This is normally handled by a load balancer. When transferring resources between cloud, gateway and resource-constrained devices, deploying identical copies of a software will not work since completely different architectures are normally used, shown in Fig 3. On server farms is 64-bit version of Linux often used on the x86-64 architecture, while gateways may run a 32-bit Linux on an embedded ARM CMU. Sensor and actuator platforms might run anything between 8, 16 or 32-bit MCUs using different architectures such as ARM, Renesas, MIPS, etc.

Research within this include topics such as:

- Seamless provisioning of services or other types of functional blocks between different types of devices.
- Security and access control, i.e. a framework for allow remote allocation and deallocation of resources.
- How to transfer identical instances of a service, or other type of functional block, across different domains, regarding to real-time performance, scalability, cost, and energy consumption.

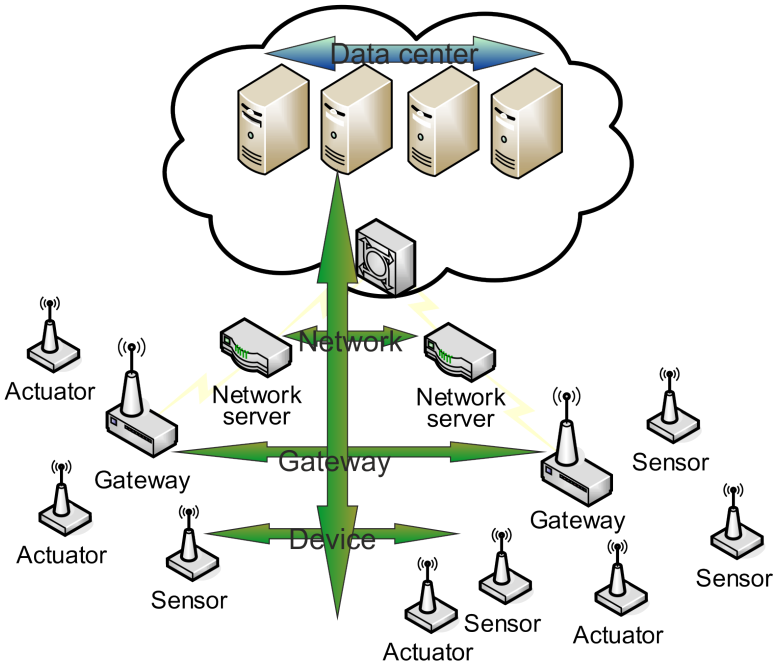

Figure 3: Elastic Service provisioning

6.4 Security, authentication & access control, accounting

The use of standardized protocols, such as IP, enables interoperability and integrability with existing, legacy and future systems. However, by using a small set of complex protocols and technologies the systems also become more vulnerable for intrusions. Hackers and malicious users can for example attack a device directly from anywhere in the world using the Internet. More complex and advanced solutions also increases the number of flaws and exploits that can be used. Traditionally when all shop floor systems were communication using non IP-based communications protocols it was very difficult to obtain access since a large number of different systems and architectures needed to be broken. When all systems and devices use one common network protocol such as IP and TCP/UDP, it becomes more open and thus vulnerable. Flaws and exploits, such as Shellshock and Heartbleed, have shown then even the most trusted commodity softwares, e.g. ssh and Bash cannot be completely trusted.

There are needs to perform research in at least the following fields:

- Encryption for low-latency communication on resource-constrained devices
- Access control and distributed authentication
- Accounting and methods for payment when using concepts such as Sensors as a Service.

7 Conclusions

Its is clear from analyzing strategic agendas and current research trends within the European union, US, and elsewhere in the world that there is an industrial revolution happening. The third generation automation systems, based on micro-electronics, is being replaced by Cyber-physical systems, where each component is able to monitor itself as well as communicate with other components, control systems, maintenance, etc.

The concept of Big data, where future networks will produce enormous amounts of data, is a result from several different technology breakthroughs, for example cloud computing and high-speed networks, to mention two of the most important. Cloud computing is a technology where availability and scalability (for e.g. data storage, computational power and bandwidth), and has been used to power some of today's most used services such as Google and Facebook. The automation industry has also been investigation on how the migration from legacy systems using proprietary solutions and field buses to state of the art computer-based distributed control can be realized. Today, it is starting to become possible to share data between factory shop floor devices and business systems, thus enabling global optimizations and improved maintenance for a factory process [5].

However, even though the use of standardized general-purpose technologies over legacy systems has clear advantages in terms availability, interoperability and flexibility, there are also drawbacks that arise. Perhaps the most widely known drawback is security. When industrial systems such as SCADA and DCS become IP-enabled, they also become vulnerable for attacks. The Stuxnet [6] attack on an Iranian nuclear facility sent shock-waves around the world.

Big data will be and is in fact, already, a reality. The number of devices used by consumers is believed to be in the range of more than 20 billion in less than just two decades. And the data produced by these tens of billions of devices will truly, be Big! But these devices will not also produce and consume large amounts of data, they will also require a massive amount of configurations settings such as PIN-codes, passwords, certificates, models, data path endpoints, addresses, and so on...

R&D efforts are envisioned to be performed at LTU, perhaps not in processing big data, but in enabling generation of some of the future's big data, especially in industrial process monitoring and control. The very large number of networked I/O points that will be used in factories of the future will all need to be (individually) configured, services must be able to be provisioned where they make the most performance impact, services must undergo life-cycle management and be able to interact with legacy systems as well as different types of next generation SCADA and DCS systems. Here the authors foresee the need of new types of engineering tools, elasticity on service provisioning, virtual factories, and integrated simulated networks and devices.

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List of selected high impact journals and conferences/workshops

ACM Transactions on Information Systems
ACM Transactions on Intelligent Systems and Technology
ACM Transactions on Information and System Security
ACM Transactions on Sensor Networks
IEEE Internet of Things Journal
IEEE Systems Journal
IEEE Transactions on Wireless Communications
IEEE Transactions on Communications
IEEE Transactions on Automation Science and Engineering
IEEE/ACM Transactions on Networking
Internet Measurement Conference
ACM SenSys
IEEE IECON
IEEE INDIN
IEEE ETFA
IEEE ICIT