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Jakub PIZOŃ[*], *Jerzy LIPSKI* [**]

PERSPECTIVES FOR FOG COMPUTING IN MANUFACTURING

Abstract

This article discusses ongoing efforts to enable the fog computing vision in manufacturing. As a new paradigm of computing implementation of fog computing faces many challenges that open perspective of new applications within a field of manufacturing. It is expected that fog computing will be one of factors that will accelerate development of in forth industrial revolution. In this article we discuss the perspectives of manufacturing companies surrounded by new solutions of CPS, CPPS and CM in relation to fog computing.

1. INTRODUCTION

The rapid development of technology, related to the progressive integration of systems and incredible growth of mobile devices number that sends and receives data, further extending quantity of solutions that implements Internet of things (IoT) and cyber-physical systems (CPS) paradigms, increase demand for computation recourses.

Cloud computing (CC) paradigm is in many cases the answer to this extensive need to process and analysis rising data volume. CC mainly provides scalable computation resources to meet customer computing power needs in service model "pay-as-you-go" which means that the fee is charged only for what is used. Computation resources are provided from the level of data centers located globally, depending on capabilities of data centers provider.

[*] Lublin University of Technology, Department of Enterprise Organization, Nadbystrzycka 38, 20-618 Lublin, Poland, +48 81 538 44 80, jakub.pizon@pollub.edu.pl
[**] Lublin University of Technology, Department of Enterprise Organization, Nadbystrzycka 38, 20-618 Lublin, Poland, +48 81 538 44 80, j.lipski@pollub.pl

CC provides a fully functional virtual environment setup that meets performance requirements. Moreover, this setup is available immediately for a price much lower than investment in raw infrastructure that is purchase of new equipment, implementation, configuration and maintenance only to obtain a new computation power.

However, a problem arises when the power of the cloud becomes unavailable or unusable due to the network unavailability, overfull bandwidth transmission or delays associated with data transmission.

These problems may appear due to the fact that a given geographical area is not available to broadband network. Control solution implement in the cloud requires huge data stream from sensors to take action in real case scenario like Smart Connected Vehicle (SCV), autonomous cars, smart cities, industrial automation and Industrial Internet of things (IIoT).

The conclusion that comes from above is that IoT like solutions force us to adopt “system view”, rather than an “individual view” of the endpoints (Bonomi, Milito, Natarajan & Zhu, 2014).

There is, for these reasons, a need for looking for some architecture framework that will support future solutions. Attractive option is Fog Computing paradigm which is presented in this article. It is considering the perspectives of implementing a framework inside requirements and characteristics of modern manufacturing.

2. FOG COMPUTING

Fog Computing is a highly virtualized platform that provides compute, storage, and networking services between end devices and traditional Cloud Computing Data Centers, typically, but not exclusively located at the edge of network. Fig.1 presents the idealized information and computing architecture supporting the future IoT applications, and illustrates the role of Fog Computing (Bonomi, Milito, Zhu & Addepalli, 2012).

Gartner Inc. forecasts that 6.4 billion connected things will be in use worldwide in 2016, up 30 percent from 2015, and will reach 20.8 billion by 2020. In 2016, 5.5 million new things will get connected every day (Van der Meulen, 2015).

With regard to this challenging increase in the volume of data generated from millions of new connected devices in terms of smart connected vehicles, autonomous cars, smart cities and industrial Internet of things systems it no longer makes sense to ship all of this data to the Cloud for processing and storage.

In such cases, it begins to be important what is sent and processed in the cloud. Question arises whether the data sent to the cloud is relevant and consistent with the established objectives and the interests of implemented system? What if some part of the data will be processed at the network edge and only critical data will be pushed to cloud? This is where fog computing is proposed.

Keeping the data at the edge of the network, where the connected devices are creating the data offers the possibility to create new and innovative services and process efficiencies not possible with Cloud computing alone.

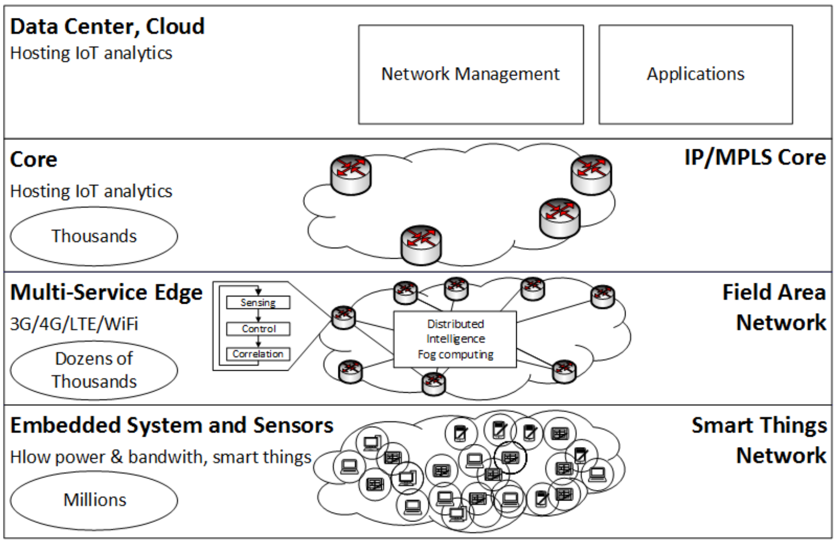

Fig. 1. The Internet of Things architecture and Fog Computing (Van der Meulen, 2015)

Smart solutions will make use of "horizontal" Machine-to-machine (M2M) connectivity in the same way traditional M2M systems typically rely on "vertical" Machine-to-Cloud (M2C) communication only (*Vortex Fog*, 2016). That is presented on Fig. 2.

The idea of implementing fog computing is proposed to deal with problem of data geo-distribution and data flow. Growing volume of raw and processed data cause the need to differentiation among data in the way that accurate data of interest will be directed to right place.

In this situation the fog collectors at the edge ingest the data generated by grid sensors and devices. Some of this data relates to protection and control loops that require real-time processing (from milliseconds to sub seconds).

This first tier of the Fog, designed for machine-to-machine (M2M) interaction, collects, process the data, and issues control commands to the actuators. It also filters the data to be consumed locally, and sends the rest to the higher tiers.

The second and third tier deal with visualization and reporting (human-to-machine [HMI] interactions), as well as with systems and processes (M2M). The time scales of these interactions, all part of the Fog, range from seconds to minutes (real-time analytics), and even days (transactional analytics). As a result of this the Fog must support several types of storage, from ephemeral at the lowest tier to semi-permanent at the highest tier. It also mention that the higher the tier, the wider the geographical coverage, and the longer the time scale.

The ultimate, global coverage is provided by the Cloud, which is used as repository for data that has a permanence of months and years, and which is the bases for business intelligence analytics. This is the typical HMI environment of reports and dashboards presenting key performance indicators (Bonomi et al., 2014).

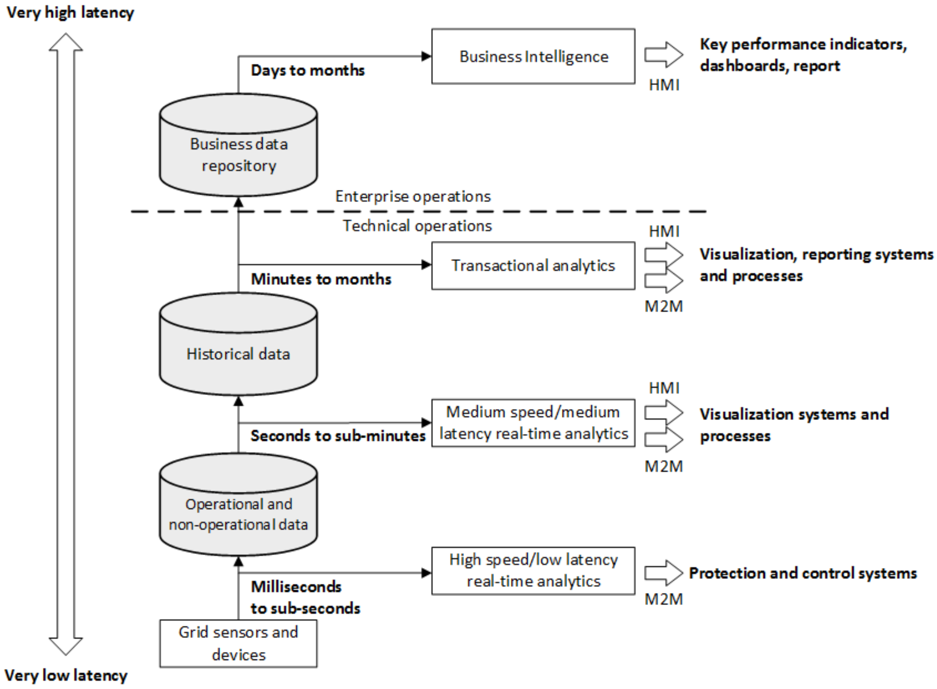

Fig. 2. Data flow in fog computing (Bonomi et al., 2014)

While the fog nodes provide localization, therefore enabling low latency and context awareness, the cloud provides global centralization that opens perspective to new innovative solutions.

The idea is not to replace the existing Cloud architectures but to enhance a system by ensuring that critical data that is available to the places where it can add most value. A Fog computing architecture can help to assure the required determinism and efficiency 'at the edge' by reducing latency and by improving Quality-of-Service (QoS) leading to improved services and a better user experience (*Vortex Fog*, 2016).

In other words, Fog complements of the Cloud, do not substitute it. For the large class of Cloud intended applications the economy of the scale (OPEX, pay as you go model) cannot be beaten. Binding these considerations it is obvious that CC model is critical for new application architectures. On the other hand, fog questions the model's universal application as a platform in relation to emergent IoT applications demand (Bonomi et al., 2014).

3. MODERN MANUFACTURING

Modern shape of manufacturing systems has been formed by successive industrial revolutions (Fig.3). Nowadays manufacturing is affected by many factors related to materials, methods, standards or even political and economic aspects. It is noticeable that growing role of integrated manufacturing information systems support manufacturing processes. Integrated manufacturing systems are organized systems in a way of interrelated production factors supported with the use of integrators (mostly computer systems). The integrators are used for the optimization of production and the products quality, tailored to market requirements and implemented with suitable use of productive resources. The integration made in order to achieve greater added value and to avoid a customer expectation mismatch is determined primarily by complexity of the modern manufacturing processes and products (Szczubełek, 2014).

These days' modern manufacturing support systems development is focused on the implementation of the latest information technology solutions related to leading trends in field of communication, data processing and mobility. These trends are:

- Internet of things – paradigm implying cyber-physical systems development, which are the basis for the development of ideas like Industrie 4.0 (Germany) and Smart Manufacturing (USA)
- Cloud computing paradigm that enables the development of solutions which provide remote access to computing power
- Big Data – methods used to analyze large sets of structured or not structured data.
- Mobility, unmanned and remote operations contribute to the development of automated control. No operators mean lower costs and possibility to fully monitor and interact with the process from anywhere at any time. That gives you the opportunity to control production in the enterprises scale or even globally (Harjunkoski, 2015).

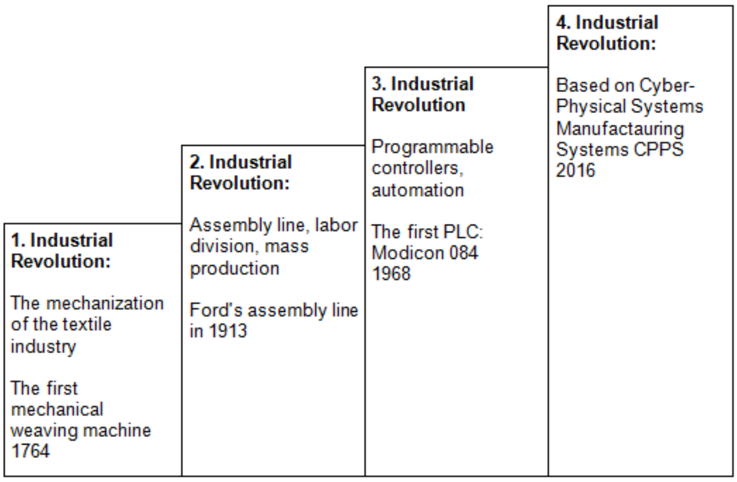

Fig. 3. Industry revolutions (Monostori, 2014)

3.1. Industry 4.0

Industry 4.0 is a strategic initiative of the German government that was adopted as part of the "High-Tech Strategy 2020 Action Plan" in 2011 (Kagermann, Wahlster & Helbig, 2013). In Germany, a major debate on Industry 4.0 has started, which in the meantime has also spread to other countries, like the US or Korea. The idea behind this term is that, the first three industrial revolutions came about as a result of mechanization, electricity and IT. Now, the introduction of the IoT and CPS into the manufacturing environment is ushering in a 4th Industrial Revolution.

In Industry 4.0, field devices, machines, production modules and products are comprised as CPS that are autonomously exchange information, trigger actions and control each other independently. Factories are developing into intelligent environments in which the difference between the real and the digital world is becoming smaller. The strong bias of the electro-technical and hierarchical world of factory automation will transit to smart factory networks, that enable dynamic re-engineering processes and deliver the ability to respond flexibly to disruptions and failures (Weyer, Schmitt, Ohmer & Gorecky, 2015).

3.2. Cyber-physical production systems

Cyber-physical systems are commonly used in aerospace industry, defense industry, power industry, transportation industry (e.g. Intelligent vehicles), medical industry (e.g. Medical devices and systems) and housing (e.g. Intelligent houses).

In a traditional manufacturing environment, where robotic systems, process control and industrial automation are universal, CPS can support both vertical and horizontal integration of IT systems, which integrate entire supply chain, or even all branches of the industry.

This ability gives a broad perspective of solutions for production systems – two-dimensional integration, both vertical and horizontal. That is a key aspect and it gives a rise to a new paradigm of cyber-physical production systems (CPPS) (Yu, Xu & Lu, 2015).

CPPS are composed of autonomous components and subsystems which cooperate in a manner dependent on the situation in all stages of production. Starts from processes that are carried out by means of production devices and logistics network. CPPS systems open prospect for building applications in different areas. The implementation of CPPS systems is identified with manifestation of fourth industrial revolution.

4. PERSPECTIVES

Modern manufacturing environment is characterized by condensation of various devices. Using more advanced and integrated machinery means greater amount of the produced data. Moreover, with the IoT sensor model implemented, the IoT amount of data increases significantly up to terabytes a day. At this point, the control and the processing of the production data gains in importance. Especially where the decision has to be fast – almost instantaneous. Therefore control decisions should be taken as close to the process being monitored, the machines or the things. The decision record should be kept inside of the company network to minimize delay associated with data transfer and storage.

Many current studies address solution to this issue to manufacturing cloud paradigm corresponding with so-called DAMA concept that is design-anywhere and manufacture-anywhere. The implementation of this concept requires the ability to easily exchange data between design and manufacturing of multiple objects remote. DAMA assumptions help to create efficient connections between systems of production planning, resource management systems and customer relationship management. Therefore, the adaptation of this concept can be implemented through types of production based on technology of cloud computing or the cloud predefined production (Cieplak & Malec, 2012).

However, manufacturing cloud is cloud computing based solution so it inherits same limitations. That creates new perspective for application systems that implement fog computing. Nevertheless the perspective of fog computing in manufacturing depends on the answer to the question whether the application of fog computing meets requirements and needs of modern enterprises. The answer to this question will be made on the basis of the analysis of fog computing key possibilities in relation to identified needs of modern manufacturing enterprises.

Modern manufacturing information system that requires computation power can be characterized with a 5C functions, which consist of Connection (sensor and networks), Cloud (data on demand), Content (correlation and meaning), Community (sharing and social), and Customization (personalization and value).

With the advent of smart sensors such as RFID technologies, collecting data for the system has become a simple exercise, but the question remains whether these devices or data provide the right information for the right purpose at the right time. The data is not useful unless it is processed in a way that provides context and meaning that can be understood by the right personnel. Just connecting sensors to a machine or connecting a machine to another machine will not give users the insights needed to make better decisions. Therefore current manufacturing systems require deeper analysis of various data from the machines and the processes (Lee, Lapira, Bagheri & Kao, 2013). Continuous analyze should be implemented to identify many invisible issues and uncertainties in manufacturing that can exist both internal and external to the factory.

Examples of internal issues include degradation of the machine and the manufacturing processes and the occurrence of failure events without any recognizable symptoms (component level). Variation of cycle time due to the inconsistent operation, unplanned systems breakdown and the presence of scraps and rework disrupt normal production planning and scheduling (system or production process level).

Meanwhile, external uncertainties, typically stemming from product development all the way through the supply chain, can manifest as: (1) unreliable downstream capacity, (2) unpredictable variation of raw materials or parts in terms of delivery, quantity and quality, (3) market and customer demand fluctuation, and (4) incomplete product design due to the lack of accurate estimation of product state during production and usage, among others.

These invisible worries and uncertainties have adverse effects in manufacturing if there are no predictive analytics and control strategies implemented. New, smarter technologies are needed for uncertainty reduction to make manufacturing more transparent (Cieplak & Malec, 2012).

The basis for solution of these problems could be the implementation of the manufacturing information system that has algorithms to support fog data processing. In this way, it opens a lot of different perspectives.

One of the key perspectives that fog computing offers is implementation of solutions that require very low and predictable latency. Cloud technology frees users from many implementation details, including the precise knowledge of where the computation or storage takes place.

This opens door for implementation of CAx (computer aided systems) engineering software in „as a service” model. CAx is a group software that support engineers with tools that simplifies and enhances their work. CAx are mostly used to develop and evaluate models of objects, products. From the technical point of view CAx requires a lot computation power to be able to be build and operate on models.

When using the Fog computing, it should be possible to share the entire package of engineering software on „as a service” model within one license model. Such possibility will facilitate deployment of working environment, provision of common repository, data versioning, empower data exchange and security.

Another perspective that fog computing opens is the possibility to implement geo-distributed applications. Fog computing infrastructure allows access to the cloud and its computing everywhere and at the edge of the network. This makes a great perspective for solutions related to technical infrastructure monitoring which is associated with the data acquisition from groups of sensors deployed on major areas. This can be particularly helpful in mining industry, petro-chemical industry (pipeline), metallurgy industry and wherever manufacture technical infrastructure is dispersed within a given geographical area.

Next perspective s are fast mobile applications like smart connected vehicle or connected rail. The proximity of the close fog computing layer opens with prospect of cyber-physical systems implementation. In this case, the virtualization is all about reproduction of equipment and machinery control parameters in virtual reality. In this way it is possible to centrally manage distributed architecture and implementation of algorithms allowing for diagnosis, monitoring, prediction of usage parts and safety in case of hacker and terrorists attacks.

5. CONCLUSION

Fog computing is emerges as an attractive solution to the problem of data processing in the Internet of Things. It relies on devices on the edge of the network that have more processing power than the end devices and are nearer to these devices than the more powerful cloud resources, thus it is reducing latency for applications (Dastjerdi, Gupta, Calheiros, Ghosh & Buyya, 2016).

That is important because of a rich interplay between the edge and the core of the network point of view, because the data generated has different requirements and uses at different time scales (Bonomi et al., 2014).

From the manufacturing perspective fog computing, due to the wide range of applications, has a high prospect of development in the field of production support systems.

Nevertheless the use of this technology to solve issues connected with production tasks execution requires the implementation of special IT ecosystem to build dynamic systems of the production data transfer.

Fog computing opens possibility to implement dynamic monitoring, control and even enable prediction manufacturing.

It should be noted that in the case of the use of fog computing paradigm in the production field it might bring effects represented as selected inventory savings, shortening the manufacturing process, better utilization of machine time and decrease in the value of work in progress.

Discussed ongoing efforts in the academia and industry in pages of this article to enable the fog computing vision still face many challenges with issues ranging from security to resource and energy usage minimization. Protocols and open architectures are also other topics for future research that will make fog computing more attractive for end users.

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