How to bring machine learning in industrial networks?

Alexis Bitaillou, Benoît Parrein, Guillaume Andrieux

How to bring machine learning in industrial networks?

Alexis Bitaillou
Université de Nantes
LS2N

Benoît Parrein
Université de Nantes
LS2N

Guillaume Andrieux
Université de Nantes
IETR

***Abstract*—Industry 4.0 opens new opportunities and challenges. One of these challenges is to provide a set of open and standardized technologies. The long life IT technologies such Ethernet and Wi-Fi can be considered as potential candidate. In this article, we present the industry 4.0 and related technologies like historical and candidate network technologies for the industry, IIoT and cognitive networks. We propose a concept using cognitive networks combined with machine learning to make IT networking technologies compliant with industrial requirements.**

***Index Terms*—Industrie 4.0, industrial networks, machine learning, cognitive networks, wireless network.**

I. Introduction

To stay competitive, industries have to create value added. As more and more industries master industry 3.0, a new kind of industry is emerging: the industry 4.0. Industry 4.0 has several ambitions, for example to optimize resources. It based on Internet of Things (IoT) and Cyber-Physical Systems (CPS). Technically, industry 4.0 has opened new challenges. One of them is to adapt IoT to the industrial environment. Industry has particular constraint such as very low latency, high reliability and security. There are a lot of industrial network technologies. Even if operational technology (OT) and information technology (IT) are merging, the constraints and requirements are not the same. We will start by the technical background of our proposition.

II. Background

A. The fourth industrial revolution

The industry of future has been a subject of research since its first formalization in 2013 in Germany [1]. Its name is different following the country. For examples, the industry of future is called *Industrie 4.0* in Germany, *Made in China 2025* in China and *Nouvelle France Industrielle* in France [1], [2]. The main objective stills the same: make the industries more competitive by increasing the value-added and optimizing resources and processes. The common causes are the high cost of labour, more generally the high operating cost, and the competition of others countries' industries. The fourth industrial revolution is based on Industrial Internet of Things (IIoT), cyber-physical systems (CPS), manufacturing digitalization and integration of trends of IT (e.g. big data). We will take the case of German Industrie 4.0. Industrie 4.0 has several simple ambitions. The first step is to optimize efficiency of manufacturing processes and resources. For example, electricity could be saved by switching it off during breaks and week-ends. One of the ambitions is to use a unique set of standardized and open technologies. This recommendation is important because it lets companies choose the technologies they need. The others ambitions are about cyber-security, safety and in-house training for workers. Industry 4.0 opens new challenges such as smart manufacturing, the construction of network environment or CPS integration [3], [4]. There are already researches on some of those topics. For example, the cloud manufacturing can be considered as a prototype of smart manufacturing [5].

B. Industrial Internet of Things

According to the ITU-T Y2060/Y.4000, the Internet of Things (IoT) is "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" [6]. The Industrial Internet of Things (IIoT) is industrial version of IoT. The IIoT is composed of sensors, actuators and other cyber-physical systems. The IIoT has several purposes the industry's processes and management. Shrouf *et al.* [7] proposed using IIoT to increase energy efficient of manufacturing. This approach consists in monitoring and analysing energy consumption. After the analysis, a strategy data-driven can be applied. Another element of Industry 4.0 is to limit down-time. Xu *et al.* [8] proposed using things like sensors to monitor production equipment and machines. Then they used tools like big data in order to predict fault. A preventive maintenance can be done before the predicted fault and potentially reduce the down-time. IIoT can help in a key point of Industry 4.0: the automation. The cyber-physical production system could be seen as the coupling of the robotics et IIoT [9]. The "IT world" has the challenges to connect the Industrial Internet of Things with the rest of the IT structure.

C. Networks

Historically, industrial networks are composed of wired elements. Technologies such as RS232 or CAN have been well tested for years. However, cables involve a low mobility and high deployment cost. These requirements are not fully compatibles with the industry of future and its needs of high flexibility [10]. They still present in industries because they are considered as reliable, effective and safe. Alternatively, several wireless technologies have appeared. They are more and more reliable and faster and faster, IEEE 802.11 for example. There are a lot of potentially industrial technologies [11].

We start with wired technologies. In wired technologies, there are two main categories: the field buses and the Ethernet-based technologies. The field buses gather at least a dozen of standards [12]. FIP, PROFIBUS, CAN and many others belong to this category. Since 2000, several field bus providers have incorporated Ethernet to their solution. Concretely, their solution consists of using Ethernet with their add-on. As Ethernet had not supported real time, the add-on provides real time and sometimes isochronous support. For example, SERCOS III, PROFINET and EtherCAT are Ethernet-based technologies. Since 2011, Ethernet has been improved to support real time but isochronous stills not supported.

We will start by low range wireless technologies. The main technologies in this category are RFID, IEEE 802.15.4 and Bluetooth. IEEE 802.15.4 is the base of WIA-PA (Wireless Networks for Industrial Automation–Process Automation), WirelessHART and ISA100.11a, three industrial wireless technologies [13]. RFID gathers several ISO standards, from electronic article surveillance to contactless smart card. For example, RFID can be used logistics for object tracking. With a range between 100 m and 250 m range, IEEE 802.11 is the only middle range wireless technology. However, IEEE 802.11 is not design to industrial networks. Its non-determinist nature and its “high” power consumption are its principal default for industrial usage [14]. IEEE 802.11ah is designed to machine-to-machine (M2M) communications [15]. It overcomes power consumption problem but the bandwidth is low (8 Mbit/s max.).

Historically, cellular networks are not design for industrial purpose. The power consumption is quite high, so devices on battery have short life. LTE-M, Narrowband-IoT (NB-IoT) and EC-GSM-IoT have been included in the LTE standard [16]. All of them are compatible with M2M. Their bandwidth is lower than “classical” LTE (e.g. 3 Mbit/s for LTE-M2), but they extend battery life. LTE-M, NB-IoT and EC-GSM-IoT can fully reuse already deployed 4G networks. This kind of technology is use in smart grid for example.

With the Internet of Things, a new kind of long range has appeared: the Low Power Wide Area Networks (LPWAN) [17]. Their range comes from few kilometres up to 40 km. Their bandwidth rarely exceeds 1 Mbit/s. For example, LoRa uses sub-GHz ISM band (e.g. 868 MHz in EU) and 2.4 GHz ISM band. In LoRa, the maximum bandwidth is 50 kbit/s in sub-GHz ISM band and 2 Mbit/s at 2.4 GHz. The range is up to 5 km in urban area and up to 20 km in rural area. The other preponderant technology is Sigfox. The maximum range is 10 km in urban area and 40 km in rural area. Nevertheless, the maximal bandwidth is limited to 600 b/s in upstream and 100 b/s in downstream (respectively 140 and 4 messages per day). IEEE 802.15.4g and 802.15.4k are the only IEEE standards in this category. Other proprietary solutions exist such as Weightless, DASH7 and Ingenu RPMA.LPWAN can be used to check cows’ health in agriculture for example.

D. Interferences

Several wireless technologies use the same ISM bands (sub-GHz and 2.4 GHz mainly). In some situations, it creates interferences. There are two kinds of interferences: *i)* multipath interferences and *ii)* multi-user interferences. Multipath interferences appear when a wave takes different paths from the sender to the receiver [18]. To solve this problem, Bottomley *et al.* [19] proposed to use RAKE antenna. Tsai and Chang [20] proposed to use Chirp Spread Spectrum (CSS). For example, LoRa uses mainly CSS. These solutions get round the problem without cancelling multipath interferences.

The second kind of interferences is multi-user interferences (MUI). They happen when two sources broadcast in the same time. According Nobilet [21], orthogonal codes can avoid multi-user interferences. However, orthogonal codes can be broken by reflection. So, in case of reflection, orthogonal codes don’t protect from MUI and multipath interferences appear. Another solution is simply to use time division multiplexing such as TDMA (Time Division Multiplexing Access). In theory, devices can broadcast at precise moment and not at the same time. In practices, TDMA is not efficient and not scalable.

Interferences are important because they are the causes of collision. Veijlgaard *et al.* [22] shown in their experiment that interferences can increase lost packet rate up to 50% for LoRa and 60% for Sigfox. The coverage of LoRa and Sigfox also decreases inside and outside. Petrova *et al.* [23] shown that up to 90% of IEEE 802.15.4 can be discarded when IEEE 802.15.4 network and IEEE 802.11n network are concurrent. They also showed that changing the channel of IEEE 802.15.4 or IEEE 802.11n can solve the problem. This task can be achieved with cognitive radio.

E. Cognitive radio and cognitive network

The cognitive radio (CR) appeared in 1998 created mainly by Mitola [24]. It builds on the top of Software-Defined Radio (SDR). The cognitive radio has been created to add smartness in SDR. The cognitive radio transforms radio nodes from simple protocol users into smart radio domain-aware agents. In cognitive radio, nodes can reconfigure their radio settings such as power delivered, frequencies used or modulation automatically depending on the situation. In order to make this objective, Mitola created RKRL (Radio Knowledge Representation Language), a description language. With RKRL, users can define a set of settings and conditions. The nodes follow the configuration according to the tested conditions. This previous definition has been completed by Haykin in 2005 [25]. According to Haykin, CR has to make communications reliable when needed, and make efficient radio spectrum usage. Haykin also proposed using cognitive radio to solve spectrum scarcity problem. This opens new challenges about sensing, detection of users, MAC strategies and routing. Cognitive networks (CN) extent the concept of radio cognitive to support wired networks and heterogeneous networks [26]. CR focuses on physical and link layer, whereas cognitive network has the OSI stack as scope. CN can perform multi-objectives optimization, unlike cross-layer design [27]. In 2008, Manoj *et al.* [28] proposed CogNet, a cross-layer design cognitive network architecture.

III. Proposition

Our objective is to help to build the network of industry of the future. We see that the ambitions of the industry 4.0 define some constraints such as using open and interoperable technologies or the need of flexibility. As industry 4.0 is based on (I)IoT and CPS, so we need consider their particularities. The choice of the network technologies is finally oriented by all these constraints.

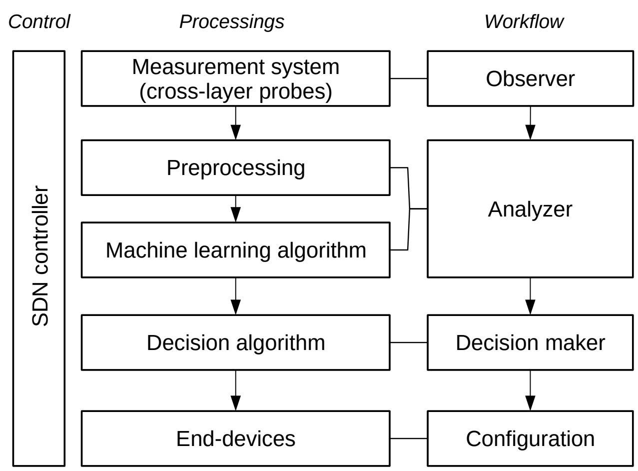

Figure 1. Proposed architecture inspired from CogNet [28].

Our solution is to use cognitive network in order to provide low end-to-end delay, low latency and a high reliability. In a cognitive network, the parameters of the OSI stack can be finely tuned to provide better performance without change the infrastructure. Optionally, our solution can consider out-of-stack parameters such as energy and security requirements. For example, it is possible to adjust the power transmission and other parameters according a policy that maximizes performance and power saving. In order to maximize the efficiency and the effectiveness of the solution, we may adopt a cross-layer design. The project MobileMAN shown the cross-layer approach can increase performance [29]. Nevertheless, the cross-layer design has some drawbacks, especially on the longevity. The number of parameters and the number of value taken by the parameters could be very high. For example, there are about 6720 possible combinations just for LoRa [30]. The choice of optimal values of the cognitive network is so not trivial. Machine learning (e.g. Deep Neural Networks, SVR) can help to guess the best parameters according the objectives. The figure 1 illustrates our proposition.

IV. Conclusion

In this paper, we presented the industry 4.0 and related technologies such as IoT, industrial networks and cognitive network. We also proposed an architecture compliant with the objectives of the industry 4.0. Our concept can be mainly composed of IT technologies such Wi-Fi, Ethernet or machine learning. Our proposition is also independent of specific or proprietary technology. We plan to validate our architecture by simulations and experimentations. The simulations will be done with software like ns2. For example, FIT IoT-LAB could be a good testbed for this kind of experimentations.

References

[1] H. Kagermann, “Recommendations for Implementing the Strategic Initiative INDUSTRIE 4.0: Securing the Future of German Manufacturing Industry ; Final Report of the Industrie 4.0 Working Group”, Forschungsunion, Tech. Rep., Apr. 2013, p. 82.

[2] L. Li, “China’s manufacturing locus in 2025: With a comparison of “Made-in-China 2025” and “Industry 4.0””, vol. 135, pp. 66–74, Oct. 2018, ISSN: 0040-1625. DOI: 10.1016/j.techfore.2017.05.028.

[3] K. Zhou, T. Liu, and L. Zhou, “Industry 4.0: Towards future industrial opportunities and challenges”, in *2015 12th International Conference on Fuzzy Systems and Knowledge Discovery (FSKD)*, Aug. 2015, pp. 2147–2152. DOI: 10.1109/FSKD.2015.7382284.

[4] Y. Lu, “Industry 4.0: A survey on technologies, applications and open research issues”, vol. 6, pp. 1–10, Jun. 2017, ISSN: 2452-414X. DOI: 10.1016/j.jii.2017.04.005.

[5] B.-H. Li, L. Zhang, S.-L. Wang, F. Tao, J. W. Cao, X. D. Jiang, X. Song, and X. D. Chai, “Cloud manufacturing: A new service-oriented networked manufacturing model”, vol. 16, no. 1, pp. 1–7, 2010.

[6] TELECOMMUNICATION STANDARDIZATION SECTOR OF ITU, “Overview of the Internet of Things”, International Telecommunication Union, Recommendation ITU-T Y.2060/Y.4000, Jun. 2012, p. 22.

[7] F. Shrouf, J. Ordieres, and G. Miragliotta, “Smart factories in Industry 4.0: A review of the concept and of energy management approached in production based on the Internet of Things paradigm”, in *2014 IEEE International Conference on Industrial Engineering and Engineering Management*, Dec. 2014, pp. 697–701. DOI: 10.1109/IEEM.2014.7058728.

[8] X. Xu, T. Chen, and M. Minami, “Intelligent fault prediction system based on internet of things”, Advanced Technologies in Computer, Consumer and Control, vol. 64, no. 5, pp. 833–839, Sep. 2012, ISSN: 0898-1221. DOI: 10.1016/j.camwa.2011.12.049.

[9] N. Jazdi, “Cyber physical systems in the context of Industry 4.0”, in *2014 IEEE International Conference on Automation, Quality and Testing, Robotics*, May 2014, pp. 1–4. DOI: 10.1109/AQTR.2014.6857843.

[10] A. Varghese and D. Tandur, “Wireless requirements and challenges in Industry 4.0”, in *2014 International Conference on Contemporary Computing and Informatics (IC3I)*, Nov. 2014, pp. 634–638. DOI: 10.1109/IC3I.2014.7019732.

[11] M. Wollschlaeger, T. Sauter, and J. Jasperneite, "The Future of Industrial Communication: Automation Networks in the Era of the Internet of Things and Industry 4.0", vol. 11, no. 1, pp. 17–27, Mar. 2017, ISSN: 1932-4529. DOI: 10.1109/MIE.2017.2649104.

[12] M. Felser and T. Sauter, "The fieldbus war: History or short break between battles?", in *4th IEEE International Workshop on Factory Communication Systems*, Aug. 2002, pp. 73–80. DOI: 10.1109/WFCS.2002.1159702.

[13] R. Zurawski, Ed., *Industrial communication technology handbook*, Second edition, ser. Industrial information technology series. CRC Press, Taylor & Francis Group, 2015, ISBN: 978-1-138-07181-0.

[14] Y. Cheng, D. Yang, and H. Zhou, "Det-WiFi: A Multihop TDMA MAC Implementation for Industrial Deterministic Applications Based on Commodity 802.11 Hardware", vol. 2017, 2017.

[15] T. Adame, A. Bel, B. Bellalta, J. Barcelo, and M. Oliver, "IEEE 802.11ah: The WiFi approach for M2M communications", vol. 21, no. 6, pp. 144–152, Dec. 2014, ISSN: 1536-1284. DOI: 10.1109/MWC.2014.7000982.

[16] O. Liberg, M. Sundberg, Y.-P. E. Wang, J. Bergman, and J. Sachs, *Cellular Internet of things: technologies, standards, and performance*. 2018, ISBN: 978-0-12-812459-8.

[17] K. Mekki, E. Bajic, F. Chaxel, and F. Meyer, "A comparative study of LPWAN technologies for large-scale IoT deployment", Jan. 2018, ISSN: 2405-9595. DOI: 10.1016/j.icte.2017.12.005.

[18] A. A. M. Saleh and R. Valenzuela, "A Statistical Model for Indoor Multipath Propagation", vol. 5, no. 2, pp. 128–137, Feb. 1987, ISSN: 0733-8716. DOI: 10.1109/JSAC.1987.1146527.

[19] G. E. Bottomley, T. Ottosson, and Y.-. E. Wang, "A generalized RAKE receiver for interference suppression", vol. 18, no. 8, pp. 1536–1545, Aug. 2000, ISSN: 0733-8716. DOI: 10.1109/49.864017.

[20] Y.-R. Tsai and J.-F. Chang, "The feasibility of combating multipath interference by chirp spread spectrum techniques over Rayleigh and Rician fading channels", in *Proceedings of IEEE 3rd International Symposium on Spread Spectrum Techniques and Applications (ISSSTA'94)*, Jul. 1994, 282–286 vol.1. DOI: 10.1109/ISSSTA.1994.379577.

[21] S. Nobilet, "Etude et optimisation des techniques MC-CDMA pour les futures générations de systèmes de communications hertziennes", PhD thesis, Oct. 2003.

[22] B. Vejlgaard, M. Lauridsen, H. Nguyen, I. Z. Kovacs, P. Mogensen, and M. Sorensen, "Interference Impact on Coverage and Capacity for Low Power Wide Area IoT Networks", in *2017 IEEE Wireless Communications and Networking Conference (WCNC)*, Mar. 2017, pp. 1–6. DOI: 10.1109/WCNC.2017.7925510.

[23] M. Petrova, L. Wu, P. Mahonen, and J. Riihijarvi, "Interference Measurements on Performance Degradation between Colocated IEEE 802.11g/n and IEEE 802.15.4 Networks", in *Sixth International Conference on Networking (ICN'07)*, Apr. 2007, pp. 93–93. DOI: 10.1109/ICN.2007.53.

[24] J. Mitola, "Cognitive radio", PhD thesis, 2000.

[25] S. Haykin, "Cognitive radio: Brain-empowered wireless communications", vol. 23, no. 2, pp. 201–220, 2005.

[26] R. W. Thomas, D. H. Friend, L. A. Dasilva, and A. B. Mackenzie, "Cognitive networks: Adaptation and learning to achieve end-to-end performance objectives", vol. 44, no. 12, pp. 51–57, Dec. 2006, ISSN: 0163-6804. DOI: 10.1109/MCOM.2006.273099.

[27] T. G. Dietterich and P. Langley, "Machine Learning for Cognitive Networks: Technology Assessment and Research Challenges", in *Cognitive Networks*, John Wiley & Sons, Ltd, Jul. 2007, pp. 97–120, ISBN: 978-0-470-51514-3. DOI: 10.1002/9780470515143.ch5.

[28] B. S. Manoj, R. R. Rao, and M. Zorzi, "CogNet: A cognitive complete knowledge network system", vol. 15, no. 6, pp. 81–88, Dec. 2008, ISSN: 1536-1284. DOI: 10.1109/MWC.2008.4749751.

[29] E. Borgia, M. Conti, and F. Delmastro, "Mobileman: Design, integration, and experimentation of cross-layer mobile multihop ad hoc networks", vol. 44, no. 7, pp. 80–85, 2006.

[30] M. Bor and U. Roedig, "LoRa Transmission Parameter Selection", in *2017 13th International Conference on Distributed Computing in Sensor Systems (DCOSS)*, Jun. 2017, pp. 27–34. DOI: 10.1109/DCOSS.2017.10.