Generalized IIOT Architecture for Manufacturing

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Abstract

In today's present scenario our manufacturing sectors across the globe are in a transition phase moving towards incorporating smartness or intelligence into the systems to meet their goals before their competitor reaches, in this phase, they are trying to incorporate some concepts like IIoT (Industrial Internet of things), M2M(Machine to Machine), IoE(Internet of Everything), CoT(Cloud of things) e.t.c. In this paper, we are going to discuss how some of these above-mentioned technologies can be added to our present manufacturing systems we would show end to end process of adopting these technologies and we would see a brief challenges we may have to face during this transition phase.

Keywords
IIOT, Protocol, Architecture,Intelligence and analytics.

1. Introduction
As we can see from our daily lifestyle each day a new product gets launched into the market and at the same time a recently released product gets obsolete. If we notice one thing from this, there is a tremendous increase in the number of manufacturing products along with this the manufacturing sector also needs to catch the trend going on in the market.

Here comes the scenario where most of the developed nations develop new concepts like Industry 4.0, Made in China, Japan 2025, etc. and most of the prominent multinationals come into the picture and started developing new technologies which would help them to reach the above goal.

At the same time the literature on different technologies like "industrial internet of things", "digital twin", "CoT (Cloud of Things)", "M2M (Machine to Machine)", and "cyber-physical system for manufacturing", etc. evolved. We have compared the popularity score of different technologies in the manufacturing sector from 01-Jan-2015 to 01-Jan-2022 with the help of Google trends, as indicated in Figure 1. we can see that there is remarkable trending popularity for the industrial internet of things.
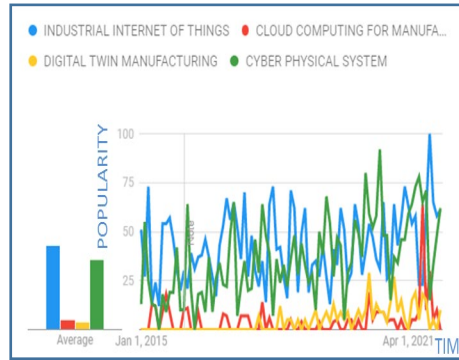
Figure 1. Different technologies in the manufacturing sector

There are so many literatures available that shows, how the sensor can be classified, which networks would be good enough to support, and how to choose a sensor for our requirement, based on environment or based on business application, one of the interesting paper indicated how to classify devices, in this paper, they classified devices into namely 6 categories like Industry sector; Device location; Device characteristics; Connectivity ;Device technology; User type. Each of the categories was further classified into a tree kind of structure which is helping us to choose wisely the best device suited for our applications (Čolaković and Hadžialić 2018).

But there is very few literature that show us end-to-end connectivity in IIOT, so primarily our paper would try to fill that literature gap.

2. IIOT Architecture

There are different types of architectures followed by different standard bodies, but every architecture is been derived or simplified from OSI (Open Systems Interconnection) architecture. It's a reference model defined by ISO. This paper is based on the 5 layers architecture of IIoT, and for every layer, there would be a security and a management layer, (Saqlain et al 2019.)as it's shown in Figure 2 and Figure 3.
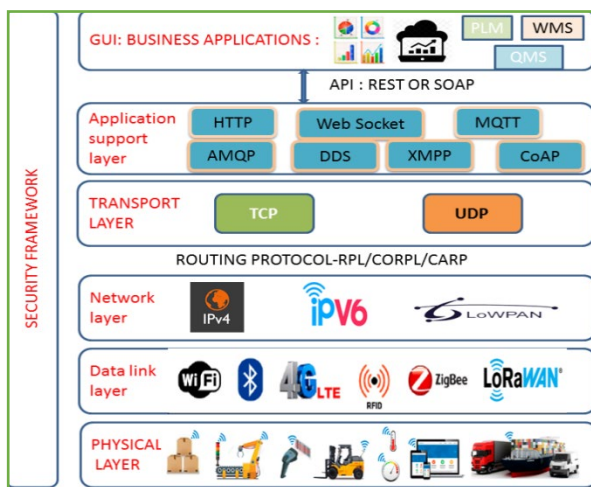

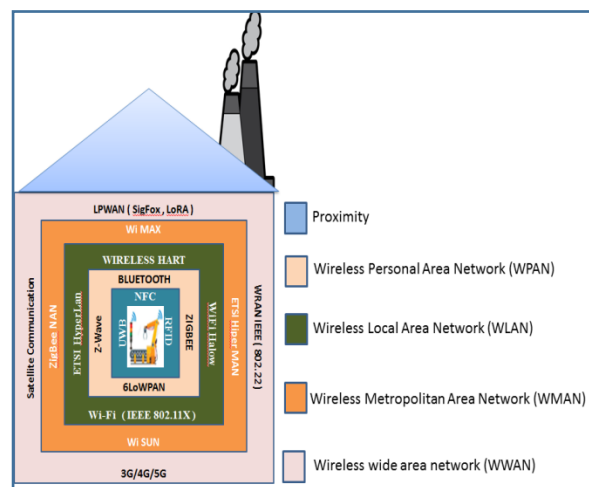Figure 2. 5 layer IIoT Architecture

Figure 3. Communication protocol distinguished on the basis of range

2.1 Physical layer

It is the layer, which has been deployed at the plant level and is responsible for generating the data at the industrial level, this level consists of sensing, and actuating devices. This layer generally sends us the raw data to the upper

layer and this happens in real-time. Each physical thing or object has unique identification such as electronic product codes so that one operate, control, or identify it individually. In some of the industries in this layer, it's locally sorted out to remove the less important data and at the same time, they can reduce the storage and transmission costs.

2.2 Data link layer

Generally, this layer connects two sensors or a gateway to a group of sensors connected to the internet. Consists of further 2 sub-layers namely: Logical link control (LLC) or Data Link Control (DLC).
Sub layer LLC Takes the network protocol data and adds control information to deliver the packet to the destination that maintains flow control.
The media access control (MAC) sub-layer directly interacts with the physical layer and its roles are data encapsulation and media access control.
There are so many data communication protocols available and they can be easily distinguished based on frequency, range, data rates, power consumption, applicationetc. Some of them have been distinguished based on the range as shown in Figure 3.

2.2.1 Bluetooth

This is a modified Bluetooth smart made for short-range communication protocol. Low latency and fast transmission are the specialties of this protocol. It follows master/slave architecture. (Frank et al 2014.)This master is responsible for waking up the nodes and it's also responsible for scheduling, generally, nodes in this protocol are awake when they are communicating and otherwise they go to sleep to save power.

2.2.2 IEEE 802.11 ah

This is the modified version of IEEE 802.11 Wi-Fi, developed to support IoT devices with low power consumption and less frame overhead over it. This is also called Wi-Fi HaLOW.
   Some of the most important features of these are(Shah and Narmavala 2015):
- In the previous version of IEEE 802.11 frame size was about 30bytes and it's been reduced to 12 bytes in IEEE 802.11ah.
- The acknowledgment frame which is around 14byte size and generally does not contain any data was replaced with a tiny signal in IEEE 802.11ah
- It has more sleep time compared to the previous versions and it wakes up only for sending the data. This is done with the help of bidirectional packet exchange as soon as it delivers the packet and receives its acknowledgment it again goes to sleep.
- It has proper synchronization during the delivery of the packet it only allowed sending the information whichis valid and complete otherwise it has to wait for a while to completely gather valid information.

2.2.3 IEEE 802.15.4

This standard is also known as the Low rate wireless personal area network (LRWpan) and this standard defines how a node can interact with each other, and it defines a format for the frame which includes the source and destination addresses. It also defines when a node can sleep to save power. But this standard does not say anything about scheduling so there should be a scheduling manager to look over this. To know whether connectivity still exists. we can use an acknowledgment system and it allows us to send two frames over two different frequency ranges (generally referred to as channel hopping).

2.2.4 ZigBee

Zigbee is designed for a large range. It supports different network topologies like a peer-to-peer,star etc. in this a coordinator is present to control the network, and it's the central node in a star topology, and its the root in a tree or cluster topology, and it may be located anywhere in peer-to-peer model. ZigBee has defined two stack profiles:one is ZigBee and other is ZigBee Pro. ZigBee Pro has offered most prominent features like, scalability is achieved using stochastic address assignment, and better performance can be achieved using many-to-one routing mechanisms, and security was tightened using symmetric-key exchange
There are still so many upcoming and developed communication protocols we have discussed only a few which have been widely used.

2.3 Network layer
2.3.1 IPV6

This is an advanced version of ipv4, this was developed so that due to the exponential growth of technology the addresses available were already saturated.Ipv6 some of the important features of them are like they provide large address space and In this header is being represented in a simplified format. Routing became faster in this as all the useless information is stored at the end of the header frame.

2.3.2 6LowPAN
This was developed because ipv6 was consuming large memory and bandwidth, with the help of this packet were able to transport with the same ipv6 addressing but this requires an additional adaptation layer which is responsible for the fitting of ipv6 into IEEE802.15.4 standards(Palattella et al. 2013). To reduce the transmission overhead the headers and compressed and fragmented to meet the requirements such as hopping (Ko et al. 2011).

2.4 Transport layer
TCP and UDP are the two most important protocols present at the transport layer.TCP stands for Transmission control protocol and UDP stands for user datagram protocol. In the case of TCP it first sets up a virtual circuit before transmitting the data and whereas UDP transmits data directly to the destination without knowing whether the receiver is ready or not. TCP is connection-oriented whereas UDP is a connectionless protocol. The rate of transmission is high in UDP but it's not a reliable one, at the same time TCP is slower but it's reliable. The size of the header is larger in TCP as compared to UDP. The best thing about TCP is that it waits for the acknowledgment of data and it also can resend the lost packets whereas UDP does not take any acknowledgment.

2.5 Application layer
There are so many protocols available in this layer, some of the most important ones are tabulated in a comparative table as shown below in Table 1. We have taken a reference diagram that indicates how IIoT has to be employed at the manufacturing level along with security firewalls.

Table 1.Comparitive table on different protocols

Application Protocol	Restful	Transport	Public Subscribe	Request Response	Security	QoS	Header size (byte)
CoAP (Constrained Application Protocol)	Y	UDP	✓	✓	DTLS	✓	4
MQTT (Message Queuing Telemetry Transport)	N	TCP	✓	✗	TLS/SSL	✓	2
MQTT-SN (MQTT For Sensor Net- works)	N	TCP	✓	✗	TLS/SSL	✓	2
XMPP (Extensible Messaging and Presence Protocol)	N	TCP	✓	✓	TLS/SSL	✗	-
AMQP (Advanced Message Queuing Protocol),	N	TCP	✓	✗	TLS/SSL	✓	8
DDS (Data Distribution Service)	N	UDP	✓	✗	DTLS	✓	-
HTTP(Hypertext transfer protocol)	Y	TCP	✗	✓	SSL	✗	-
WEBSOCKET	Y	TCP			TLS/SSL		6

3. Incorporating Intelligence
The next step after sending data to a cloud or local database is that we have to incorporate certain smartness into the system, this can be achieved with the help of AI, ML, and Deep learning algorithms, below this we have discussed a seven-step approach of how to easily incorporate intelligence to the system(Lin et al. 2017).
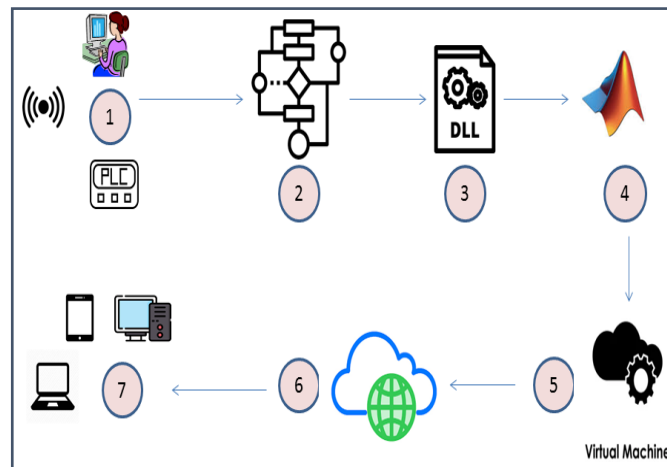
Figure 4. 7-Steps approach towards incorporating intelligence

There are seven easy steps for incorporating intelligence into our manufacturing system. (Figure 4)

Step 1: It consists of the deployment of data at the local level.

Step 2: Think of a proper suitable Algorithm that can be easily deployed using the Matlab toolbox and save that source file with the extension of .m.

Step 3: Now convert the above .m file into a DLL .net file (A DLL is a library that contains code and data that can be used by more than one program at the same time.)Using deploy tool in Matlab. Here it assumes the Microsoft.NET programming language to be the default Run time for .net programs.

Step 4: Now we should Upload MATLAB Compiler Runtime, to our cloud storage which is a royalty-free service. The uploaded compiler would help us to execute our saved files even though our computers may not have installed MATLAB.

Step 5: Upload the Algorithm functions which were developed in Step 3 to virtual machines in the cloud. So that it can be used as a cloud function and now download and install the MCR to the virtual machines which are holding the predictive algorithm functions.

Step 6: Now create a cloud service that would have all the above-discussed algorithms and compilers which helps us to enable the cloud services for manufacturing.

Step 7: The users with proper authority can now avail these services from the cloud through with the help of internet through various mediums and whenever they require it.

4. Graphical User Interface

After incorporating intelligence into the system now we show the user results in form of nice graphs, piecharts, etc. The Figure 5 Indicates the ongoing project of our workshops user interface where legacy machines are going to be made as an IIoT enabled with a reasonable cost and the data collected form there is used for analysing and calculating the KPI,and the end-user has the permission to see certain things like the status of the machine (whether its running or not) the performance is KPI(indicates how much it has worked in 24 hrs), it also shows alarms, part program, machine power, spindle speed, and spindle motor temperature, etc(Tao et al.2014).

Figure 5.User interface for workshop equipment management

The key challenges arising during incorporating IIoT in a manufacturing firm are(Čolaković and Hadžialić 2018):

I.   Due to heterogeneous objects, it's becoming difficult for everyone to come on to one platform and most companies follow their architectures and methods of integrating layers and keeping their methods a trade secret leading to a huge variety of devices/objects. In one way it increases competition among them but in the other way, they are not following a fixed architecture by which a consumer is being forced to use it even if he is not desired.

II.   It's becoming very difficult to control the flow of traffic and researchers are trying to find the best traffic path.

III.   Sometimes difficulties are faced during the transmission due to network, bandwidth, etc. problems, and also sometimes there are loss of packets during transmitting data to the cloud and there is a loss of real-time applications

IV.   Data storage, the type of data collected and managed is also becoming difficult, in these recent trends there are some applications developed to overcome this problem.

V.   For one to choose a correct IoT model there is no metric (like power consumption, network latency, RAM required, CPU computation capability)and there is no literature available so the challenge comes here of developing a mathematical model with a simulation that would help one to get the perfect fit to the system.

VI.   Algorithms are yet to be developed which would optimize the load distribution between the sub-components.

VII.   Developing a secure and well-established smooth flow of private networks is also becoming a challenge in this current scenario.

5. Conclusion

Many such protocols have been developed by ITU, IETF, IEEE and other organizations and many more are in development. Due to their large number, there consisted a dilemma in choosing, so we have tried to relate it with the industries. This paper aims to give an insight to developers to develop an end-to-end (From the beginning of the sensor transmitting data to the end of the user interface) approach for manufacturing. At last, we have briefly discussed some trending challenges that researchers are trying to solve.

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Biographies

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