Architecture and Network Design for Industrial Internet of Things

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Abstract. The aim of the paper is to provide the best architecture and the most suitable network design for companies that are working in the space of Industrial Internet of Things. The architecture of internet hourglass model and method for selecting the Industrial Internet of Things network protocol is proposed and tested in this paper. The network design model is called as three-dimensional network design space which includes battery life, device data rate, and device to gateway range. Different industry accepted and globally available wireless network protocols are tested to define the best network protocol for Industrial Internet of Things. The hypothesis experiment and research results for the architecture model are directly implied to the practical benefits for industrial companies.

Keywords: Network design · Architecture · Industrial Internet of Things · Industrial management · Innovation

1 Introduction

Industrial Internet of Things (IIoT) is a network of connected devices like sensors, machines, smart devices, and other physical objects which tie to central cloud-based network servers. The network has the competence to monitor and control the functionality of the machines [1, 2]. The architecture and the framework for IIoT become a presidential requirement which defines the backbone for the IIoT system for all industrial enterprises.

IIoT based solutions has specific requirements for network communication like range, power consumption, etc. There are many network protocols which are available in the market for industrial applications depending upon the different network coverage area, are shown in the Fig. 1 [2].

This paper concentrates on the network connectivity and architecture for IIoT deve-lopment. Furthermore, the paper proposes the three-dimensional network design model to find the best network protocol and provide hypothesis results for selecting the ideal architecture model that will work for different IIoT applications across different industrial companies.

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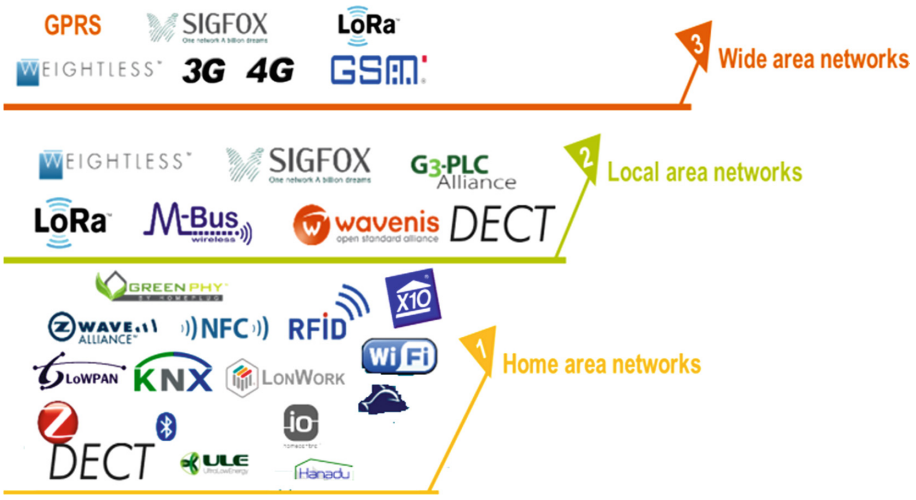

Fig. 1. IIoT wireless protocols [3, 13]

2 Architecture Model for Industrial Internet of Things

The architecture model for the IIoT can be based upon the hourglass model of the internet as it fulfils stringent IIoT requirements. The Fig. 2 shows the three key aspects for selecting an architectural model [4]:

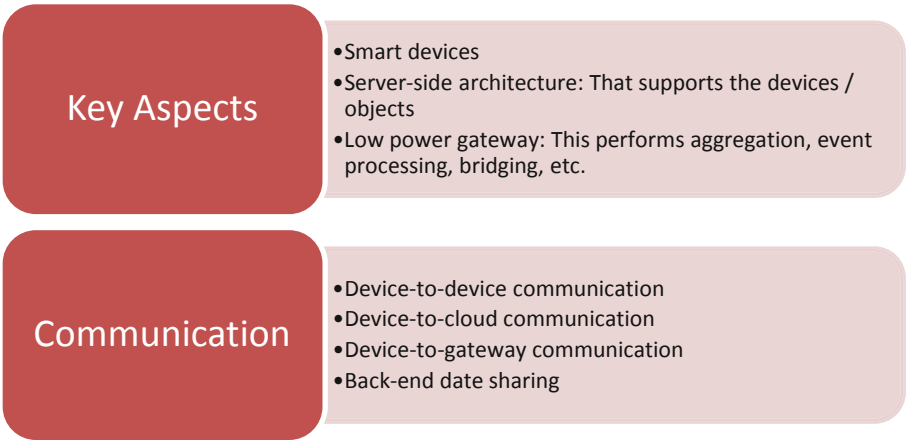

Fig. 2. Key aspects to consider while selecting IIoT architecture

IIoT is a complex system as it involves a lot of smarter, smaller sized, and heterogeneous devices which interconnect between the technology and the application layer. Furthermore, the complexity quotient is increased because of networking technology like wireless, LAN, RFID or LTE as they operate and function at different ranges [5].

The Fig. 3 shows the hourglass model for IIoT systems. The technology layer includes diverse devices and represents the handling of various networking standards and protocols. Further, at the application layer, different services like home and factory automation are readily available for the industry [5].

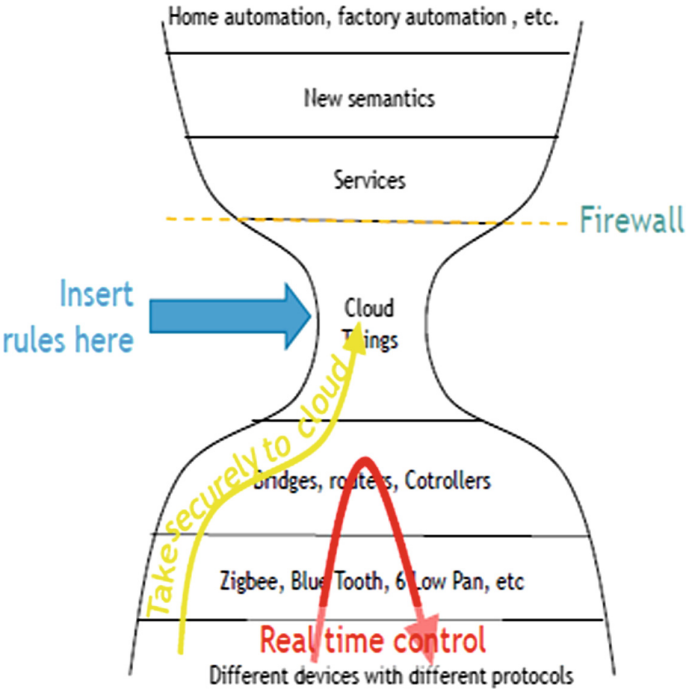

Fig. 3. IIoT architecture. Source: The Internet of Things: Roadmap to a Connected World, Massachusetts Institute of Technology 2016

3 Network Design Model for Industrial Internet of Things

From Fig. 1, in the previous section it was determined that there are wide range of different networks technologies which are available like Bluetooth Low Energy, 6LoWPAN, 3G, WiFi, LTE, IEEE 802.15.4, ZigBee, etc. Therefore, it becomes difficult to find the best protocol for all IIoT applications as some provide high performance, others are excellent technologies or they deliver better user interfaces or experiences.

The proposed network design model for the IIoT applications is referred as the three-dimensional network design model. This model will help the industrial enterprises to easily choose the network protocol for their Industrial IoT development. The model is divided into three axes as shown in the Fig. 4. The first dimension on the x-axis is the battery life, the second dimension on the y-axis is the device data rate or the duty cycle, and the third dimension on the z-axis is the device to gateway range [6].

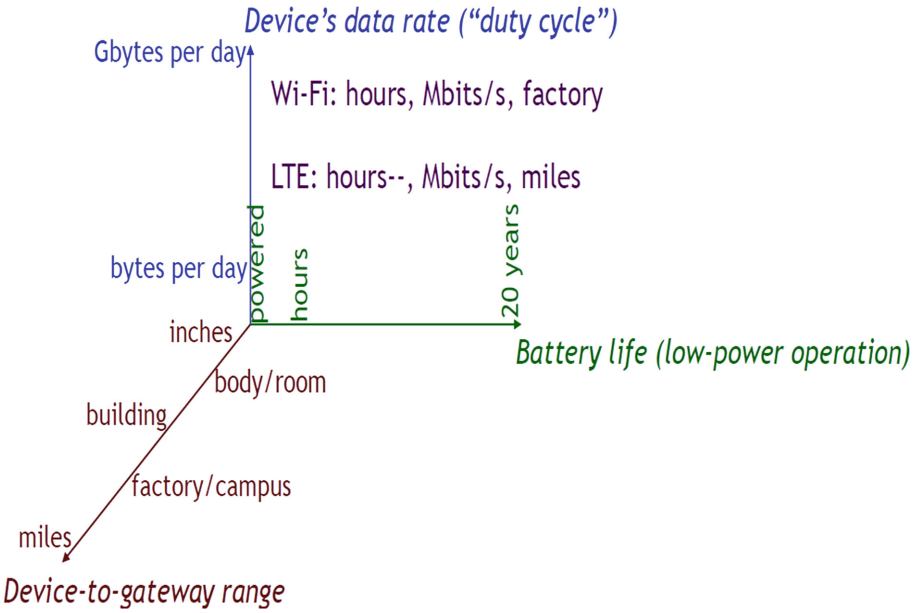

Fig. 4. Three-dimensional network design model. Source: The Internet of Things: Roadmap to a Connected World, Massachusetts Institute of Technology 2016

3.1 Comparison of Wireless Network Protocols

The selected protocols for the comparison were based upon their popularity in the industrial environment and their wide range for fulfilling the requirements for IIoT applications. Further, these protocols were placed against the three-dimensional network design model and compared. The comparison results are shown in the Fig. 5:

- **Thread:** The advantage is that it is low-power and low-cost over other protocols. Application includes mobile, device to device communication and smart home [7].
- **ZigBee:** Based on the IEEE 802.15.4 link layer and operates in 2.4 GHz ISM bank. The network layer is based upon mesh topology [8]. The applications include smart homes, smart building and home automation.
- **Wireless HART:** It is based on IEEE 802.15.4, designed for industrial applications processes – providing access to diagnostics, configuration and process data [8].
- **Bluetooth Low Energy (BLE):** It is very popular in diverse applications ranging from automobiles, fitness, audio, video, heart rate monitor, etc.
- **6LoWPAN:** Acronym for IPv6 over Low Power Wireless Personal Area Networks. A mesh network topology, large area network, reliable communication and low power consumption [7].

The comparison results are in many magnitudes of ranges that fits different technologies. Each technology has their own benefit, as some protocols have higher battery life; others have better device to gateway range, or device duty cycle. One of the best practices

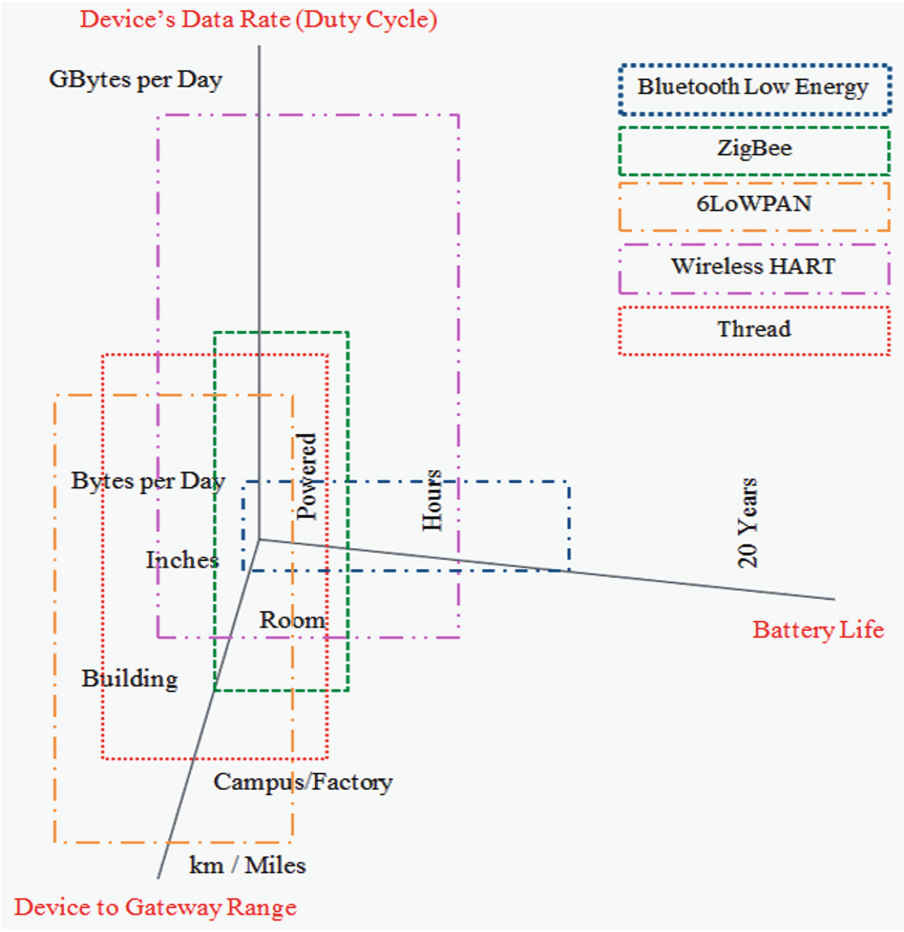

Fig. 5. Comparison results of different network protocol against the three-dimensional IIoT network design model

is to place the specific IIoT requirements against the three dimensional graph and find out the best protocol technology which met all the IIoT applications requirements [6]. Another best practice is to select any given technology or protocol and place it against the three dimension model to identify if the IIoT application requirements are satisfied.

4 Results for Industrial Internet of Things Architecture Model

To evaluate the best architecture model for the IIoT systems, the previous and current architecture models were studied and tested under different testing parameters. Furthermore, a survey was conducted across a multinational IIoT based company which specializes in industrial space including energy sector, heavy machinery, and oil and gas

industry. 117 employees from 20 countries participated in the survey to discuss if internet hourglass model is the best architecture model for IIoT. The Figs. 6 and 7, provides the survey results.

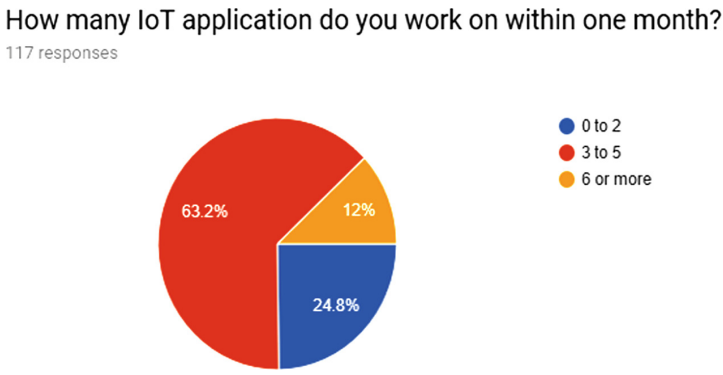

Fig. 6. How many IoT applications do the participants work in one month

The survey results showed that about 63% employees said they work with 3 to 5 application in one month. About 25% replied they work with 0 to 2 IIoT applications and whereas only 12% said they use or develop 6 or more IIoT application in each month.

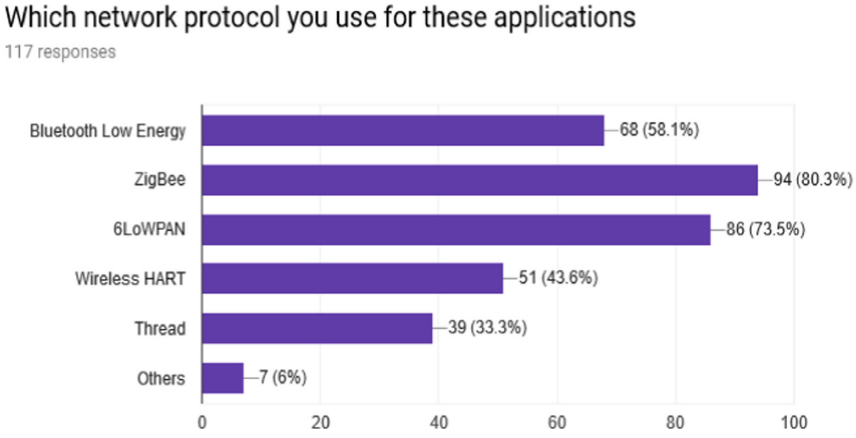

Fig. 7. Network protocol used by the company

The choices provided of all the protocols referenced in this paper were based upon the popularity of the network protocols in IIoT environment and in industrial companies. The option "others" were added if the employees do not use the above mentioned protocols in their organizations. The popular choice included all the protocols which were recommend in this paper, in decreasing order – ZigBee (80%), 6LoWPAN (74%), Bluetooth Low Energy (58%), Wireless HART (44%) and Thread (33%). Only 6% belonged to the others option. All these protocols are architecturally derived from the hourglass model

and it holds true to evaluate that the internet hourglass model is the best architectural model for IIoT.

4.1 Testing

The "Chi-Square Goodness of Fit Test" method was used to prove the test, since the sample fulfilled the following basic requirements [9]:

- The sampling method is simple random sampling
- The variable under study is categorical
- The expected value of the number of sample observations in each level of the variable is at least 5.

Hypothesis: **Internet hourglass model is the best architecture model for Industrial Internet of Things applications.**

- H0: IIoT architecture is based upon the Internet hourglass model

To evaluate this hypothesis:

- Q1: How many IoT applications do you work on within one month?
- Q2: Which network protocol you use for these applications

Parameters used:
Degrees of Freedom (DF):

$$DF = (r - 1) * (c - 1) \tag{1}$$

Where:
r: Number of levels for one categorical variable
c: The number of levels for other categorical variable

Expected Frequencies:

$$E_{r,c} = \frac{(n_r * n_c)}{n} \tag{2}$$

Where:
$E_{r,c}$: Expected frequency count for lever r of Variable A and level c of Variable B
n_r: Total number of sample observations at lever r of Variable A
n_c: Total number of sample observations at lever c of Variable B in the total sample.

Test statistic:

$$x^2 = \sum \frac{\left(O_{r,c} - E_{r,c}\right)^2}{E_{r,c}} \tag{3}$$

Where:
$O_{r,c}$: Observed frequency count at lever r of Variable A and level c of Variable B
$E_{r,c}$: Expected frequency count at level r of Variable A and level c of Variable B

Table 1. Observed values for Q1 and Q2

Q2: How many IoT applications do you work on wihthin one month?	Q5: Which network protocol you use for these applications						
Q2 and Q5	Bluetooth low energy	ZigBee	6LoWPAN	Wireless HART	Thread	Others	SUM
0 to 2	5	7	7	4	3	4	29
3 to 5	14	19	18	10	8	6	74
6 or More	2	3	3	2	1	1	14
Total	21	29	28	16	12	11	117

P-value:
The P-value is the probability of observing a sample statistic as extreme as the test statistic. Since the test statistic is a Chi-square, we need to assess the probability associated with the test statistics. This is done using the degrees of freedom [10, 11] (Table 1).
Degree of Freedom from Eq. (1):

$$DF = (3-1) * (6-1) = 10$$

Expected frequencies from Eq. (2) (Table 2):
Test statistics x^2 from Eq. (3) (Table 3):

Table 2. Expected values for Q1 and Q2

Q2: How many IoT applications do you work on within one month?	Q5: Which network protocol you use for these applications						
Q2 and Q5	Bluetooth low energy	ZigBee	6LoWPAN	Wireless HART	Thread	Others	SUM
0 to 2	5.21	7.19	6.94	3.97	2.97	2.73	29
3 to 5	13.28	18.34	17.21	10.12	7.59	6.96	74
6 to More	2.51	3.47	3.35	1.91	1.44	1.32	14
Total	21	29	28	16	12	11	117

Table 3. Test values for Q1 and Q2

Q2: How many IoT applications do you work on within one month?	Q5: Which network protocol you use for these applications						
Q2 and Q5	Bluetooth low energy	ZigBee	6LoWPAN	Wireless HART	Thread	Others	SUM
0 to 2	0.0081	0.0049	0.0005	0.0003	0.0002	0.5948	0.6089
3 to 5	0.0388	0.0236	0.0048	0.0014	0.0222	0.1317	0.2225
6 to More	0.1047	0.0637	0.0367	0.0038	0.1323	0.0760	0.4171
Total	0.1515	0.0922	0.0419	0.0055	0.1547	0.8025	1.2485

The calculated degree of freedom is 10. The calculated testing criteria or the Chi-Square value is 1.2485 and p is 0.9995 [11, 12]. Comparing the calculated testing values against the critical value, it is observed that the calculated testing value is less ($1.2485 < 18.307$). The used level of significance was 0.05.

Therefore, it is concluded that H0 is accepted; hence proving the internet hourglass model is the best architecture model for Industrial Internet of Things.

5 Conclusion

The proposed three-dimensional network design model for Industrial Internet of Things was studied and successfully placed against the popular industrial network protocols like Bluetooth Low Energy, ZigBee, Wireless HART, 6LowPAN, Thread, etc. The three-dimensional model consists of duty cycle, battery life, and device and gateway range. The best practices for using the network design for IIoT systems are:

- The network design for IIoT application is based on the terms of which technology or combinations of technology are the best suited for that particular IIoT application by placing the requirements.
- Take the three-dimensional models and place the preferred technology and see if it fits the requirements of the intended IIoT application.

Furthermore, the research objective of the paper was also to prove that the internet hourglass model is the best architectural model for the IIoT applications or systems, which was proved by conducting the survey and testing the hypothesis using the Chi-Square Goodness of Fit Test criteria.

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