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# Flexible Factory IoT: Use Cases and Communication Requirements for Wired and Wireless Bridged Networks



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DRAFT

# Flexible Factory IoT: Use Cases and Communication Requirements for Wired and Wireless Bridged Networks

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## Editor

| Name        | Affiliation                |
|-------------|----------------------------|
| Zein, Nader | NEC Europe Ltd. (NLE GmbH) |

## Nendica Chair

| Name        | Affiliation |
|-------------|-------------|
| Mark, Roger | Huawei      |

## Contributors/Supporters

| Name               | Affiliation  |
|--------------------|--|
| Hasegawa, Akio     | Advanced Telecommunications Research Institute International (ATR) |
| Kondo, Yoshihisa   | Advanced Telecommunications Research Institute International (ATR) |
| Webber, Karl       | Beckhoff   |
| Hasegawa, Jun      | Fujitsu Kansai-Chubu Net-Tech Limited                              |
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| Su, Yi             | Fujitsu R&D Center Co., Ltd.                                       |

|                     |  |
|---------------------|--|
| Marks, Roger        | Huawei   |
| Kato, Toshio        | Mobile Techno Corp.  |
| Murata, Syuuichi    | Mobile Techno Corp.  |
| Yoshimura, Masahiro | Mobile Techno Corp.  |
| Tomita, Hisanori    | Murata Machinery, Ltd.   |
| Itaya, Satoko       | National Institute of Information and Communications Technology (NICT) |
| Kojima, Fumihide    | National Institute of Information and Communications Technology (NICT) |
| Koto, Hajime        | National Institute of Information and Communications Technology (NICT) |
| Mochinaga, Mika     | National Institute of Information and Communications Technology (NICT) |
| Ohori, Fumiko       | National Institute of Information and Communications Technology (NICT) |
| Ohsawa, Tomoki      | National Institute of Information and Communications Technology (NICT) |
| Hirabayashi, Chiaki | NEC Communication Systems, Ltd.  |
| Ikenoue, Yuichi     | NEC Communication Systems, Ltd.  |
| Hayashi, Takeshi    | NEC Corporation  |
| Hidaka, Youichi     | NEC Corporation  |
| Inoue, Takamichi    | NEC Corporation  |
| Kato, Rintaro       | NEC Corporation  |
| Kobayashi, Tsukasa  | NEC Corporation  |
| Maruhashi, Kenichi  | NEC Corporation  |
| Nakajima, Taketoshi | NEC Corporation  |
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| Osuga, Toru         | NEC Corporation  |
| Zein, Nader         | NEC Europe Ltd.(NLE GmbH)  |
| Fujimoto, Takuya    | OMRON Corporation  |
| Ikumo, Masahiro     | OMRON Corporation  |
| Saito, Keisuke      | OMRON Corporation  |
| Yamada, Ryota       | OMRON Corporation  |

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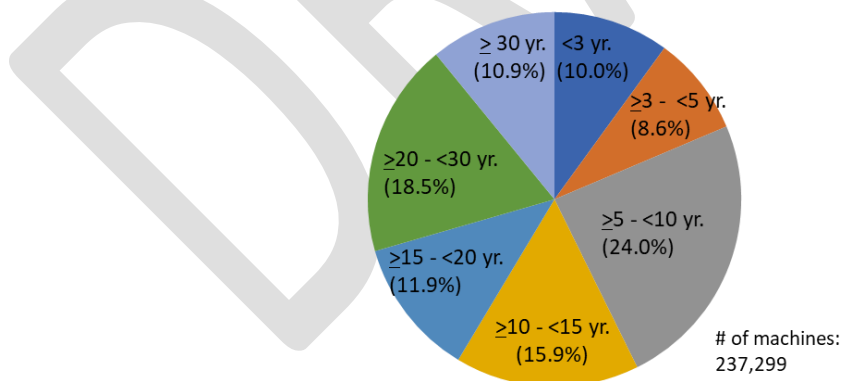
DRAFT

# 1 Flexible Factory IoT: Use Cases and 2 Communication Requirements for 3 Wired and Wireless Bridged Networks

## 4 Introduction

5 Communication in factories has until now been mainly wired communication. A survey ~~in~~[1]  
6 indicates that the market share of wired networks in factory automation is 94%. However, in  
7 recent years shorter product development cycles have demanded greater flexibility in the layout  
8 of machines and sequence of processes. There are increasing expectations for the use of wireless  
9 connectivity amongst machines in the manufacturing and factory processes.

10 When considering the network evolution within factories, consideration should take into account  
11 legacy manufacturing machines that have been in service for many decades. Within factory  
12 installations, sensors are attached to machines for the purpose of monitoring operations and  
13 preventive maintenance. According to a survey by Japan's Ministry of Economy, Trade and  
14 Industry, the lifetime of production machines is long, and about 10.9% of them have been used  
15 for more than 30 years, as shown in [Figure 1](#). In many cases, sensors continue to be used long  
16 after they have been introduced, resulting in the coexistence of sensors and their communication  
17 interfaces in different generations as well within machines.



18  
19 **Figure 1 Share of production machines by age [2]<sup>1</sup>**  
20

<sup>1</sup> Data were from a ~~questionnaire~~ survey ~~for of 1033~~ Japanese ~~1,033~~ factories administrated by Ministry of Economy, Trade and Industry of Japan in 2013. Total number of machines was 237,299, ~~in which including~~ grinders (12.5%), industrial robots (9.3%), automated assembly machines (8.8%), welding/fusing machines (8.7%), lathe machines (7.9%), press machines (6.7%), machining centers (5.5%), and others ~~were investigated~~.

1 This paper considers the need for network requirements in an evolving factory environment  
2 referred to as “Flexible Factory”. The Flexible Factory represents an evolved site for flexible on-  
3 demand manufacturing of variable product types with variable production volumes. Flexibility in  
4 the factory environment emphasizes mobility and configurability of manufacturing facilities. In  
5 support of the flexibility, human operators are engaged with the production process in order to  
6 oversee the on-demand production. This new flexibility requires the factory network to evolve to  
7 include wireless connectivity in support of increased mobility of humans and automated vehicles  
8 and the reallocation of facilities.

9 This ~~report,report~~ developed under the IEEE 802 Network Enhancements for Next Decade  
10 Industry Connections Activity (~~NEND-ICANendica~~) addresses integrated wired and wireless  
11 Internet of Things (IoT) communications in the factory environment, considering ~~its~~-expected  
12 evolution to dense radio device utilization. The report includes use cases and requirements within  
13 the factory wireless environment, with a focus on bridged Layer 2 networks. It presents problems  
14 and challenges observed within the factory and reports on feasible solutions for overcoming these  
15 issues. Topics that may benefit from standardization are highlighted.

16 The report presents an underlying ~~Eend-to-Eend~~ (E2E) network architecture ~~which-that~~ addresses  
17 the operation and control of the various services in the factory network according to their  
18 dynamic QoS requirements. It analyses the applicable standards and features in IEEE 802  
19 technologies to achieve the requirements in E2E network connectivity for integrated wired and  
20 wireless connectivity in a factory environment.

## 21 Scope

22 The scope of this report ~~is capturing~~includes use cases and communication requirements for  
23 wired and wireless bridged networks. Dense use of wireless devices with differentiated QoS  
24 requirements and ~~its~~ operation in factory environment are taken into consideration. Gap analysis  
25 from existing IEEE 802 standards and necessary technology enhancement are also covered in the  
26 context of time-sensitive networkss for the future.

## 27 Purpose

28 The purpose of this report is to document issues and challenges in managing reliable and time-  
29 sensitive connectivity in the Flexible Factory, in which various equipment is attached to the wired  
30 network via wireless connections. The report includes technical analyses of the identified features  
31 and functions in wired and wireless IEEE 802 technologies for managing requirements in E2E  
32 network connectivity. The results of the analysis lead to recommendations for enhancements of  
33 IEEE 802 standards supporting the integration of wired and wireless factory networks.~~The~~  
34 ~~purpose of this report is to understand issues and challenges in managing a reliable and time-~~  
35 ~~sensitive connectivity in “Flexible Factory” scenarios, where various equipment are attached to~~  
36 ~~the wired network via wireless connections. The report includes technical analyses of the desired~~  
37 ~~features and functions in wired and wireless IEEE 802 technologies for managing requirements in~~  
38 ~~E2E network connectivity which can be used in an IEEE 802 standard solution based on time~~  
39 ~~critical requirements for integrated wired and wireless connectivity within the factory~~  
40 ~~environment.~~

## 41 Factory Overview and ~~Operation~~-Communication Network environment

## 1 Factory communication network environment

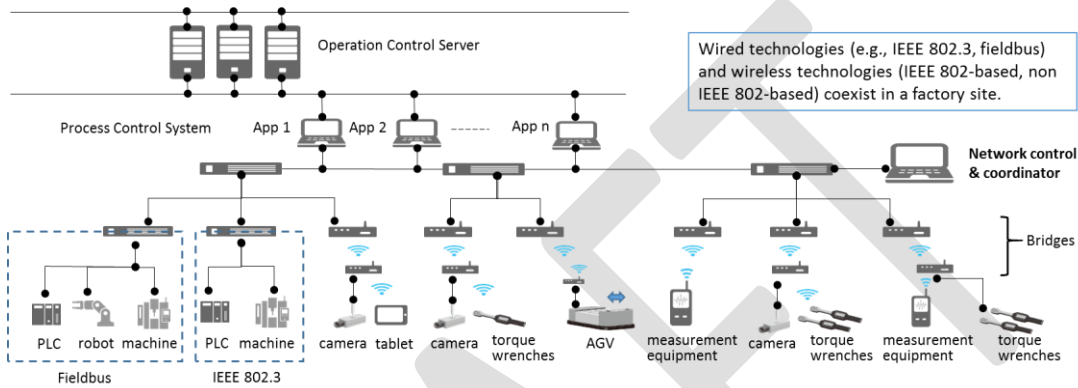
2 Trends to connect devices such as sensors and cameras to factory networks are accelerated by a  
3 strong demand for improving productivity under the constraints of pressure for cost reduction.  
4 Connection of information on production processes and supply chain management within a  
5 factory and across factories ~~has become increasingly important~~becomes important. It is also  
6 important to consider future needs of new technologies and networks deployments, ~~given in spite~~  
7 ~~of~~ the typical long life-time of any deployed technology in the factory floor. ~~Commutation~~  
8 ~~Communication~~ networks in factories will undoubtedly change in the next decade.

9 ~~Figure 2~~ shows an example of a network for a vehicle assembly line in ~~a~~ factory today. ~~The~~  
10 ~~Industrial control systems, ranging in scale are extensively applied for industrial process control~~  
11 ~~and operation. Such systems can range~~ from a few modular panel-mounted controllers to  
12 thousands of field connections, ~~providing by being the universal means of~~ remote access to the  
13 ~~enormous~~ data provided by, ~~for example, e.g.~~ sensors, actuators and motors ~~deployed in the~~  
14 ~~field~~. The larger systems are usually implemented by Distributed Control Systems (DCS) or  
15 Supervisory Control and Data Acquisition (SCADA) systems, which manage Programmable Logic  
16 Controllers (PLC) in the field. The entities labelled ~~in Figure 2~~ as 'App x' ~~illustrate indicate several~~  
17 system applications, e.g., preventive maintenance, management of materials and products, ~~and~~  
18 ~~machine movement monitoring~~monitoring of movements and machine monitors, which are  
19 ~~supported in the factory network~~.

20 The factory network infrastructure primarily ~~concerns provides~~ the communication between and  
21 within these components and systems. One of the ~~distinctive features of essential differences~~  
22 ~~between~~ factory ~~and commercial~~ networks is that the physical devices connecting to the network  
23 are used to control and monitor real-world actions and conditions. This ~~results in a strong~~  
24 ~~emphasis on differentiated~~~~has resulted in an emphasis on a different set of~~ Quality of Service  
25 (QoS).

26 ~~Due to performance and market advantages~~Because of performance and other advantages,  
27 Ethernet has emerged as the dominant standard for the ~~physical and medium-access control~~  
28 ~~layers of factory networks~~physical layer. ~~Ethernet, unlike serial protocols such as fieldbus [3],~~  
29 ~~supports multiple higher layer protocols supporting the interconnection of devices with various~~  
30 ~~bandwidth requirements, including PLCs, HMI (Human Machine Interface), and devices requiring~~  
31 ~~high speed communications~~Unlike serial protocols such as fieldbus [3], multiple higher layer  
32 ~~protocols can run on the same Ethernet physical layer. It is fairly easy to interconnect several~~  
33 ~~devices such as PLCs, HMI (Human Machine Interface), etc, remaining in high speed~~  
34 ~~communication~~. ~~In high-end industrial communication markets, the use of Ethernet has become~~  
35 ~~increasing favorable due to the introduction of the determinism based on the IEEE 802 Time-~~  
36 ~~Sensitive Networking (TSN) standards. This set of standards for bridges and bridged networks,~~  
37 ~~developed and supported by the IEEE 802.1 TSN Task Group, supports deterministic services, such~~  
38 ~~as guaranteed packet transport with bounded latency, low packet delay variation, and low packet~~  
39 ~~loss. For further information about the TSN Task Group and list of approved standards and~~  
40 ~~projects in development, see the TSN Task Group webpage [4]~~Adding on the deterministic  
41 features introduced by TSN, Ethernet are now taking over more shares at the high-end industrial  
42 communication markets.

1 ~~However, much of the cost of installation of wired networks is for the wire itself.~~ Installation of  
 2 wires in a factory environment is costly. Future industrial factory networks are expecteding to use  
 3 more wireless to ~~eliminate~~ reduce the installation cost, as well as to enhance flexibility. By utilizing  
 4 wireless communications, it is possible to collect useful information from IoT sensors, to flexibly  
 5 allocate equipment such as cameras, and to analyze the status of humans and machines. ~~#~~  
 6 Wireless is an essential element that enables flexible layout of machines and order of  
 7 manufacturing processes to adapt to variable-type, variable-volume production and mass  
 8 customization [5].<sup>2</sup>



9

10 **Figure 2 Example of network topology for a vehicle assembly line**

11 ~~The ability to transmit and receive~~ Transmitting and receiving data over a wireless link is not  
 12 always going to work with the same degree of certainty as as reliable as a wired link. More effort  
 13 will be required for wireless communication because of its limited and shared radio resources and  
 14 the sensitive nature of the environment in which it will operates.

15 In order to configure, coordinate and maintain various QoS requirements ~~E2E~~ end to end over the  
 16 heterogeneous network integrating wired and wireless interfaces, as in Figure 2, the some sort of  
 17 network control and coordinator may be considered to aid the is required. ~~The~~ successful  
 18 integration of wired and wireless systems is indispensable.

19 Within the factory network, there is a variety of traffic types generated from different factory  
 20 applications. Example of different traffic types in factory network are defined by [6]. These are  
 21 characterised as either periodic with constant bit rate or sporadic with various packet sizes. There  
 22 are a number of functions and mechanisms in the aforementioned IEEE 802 TSN standards that  
 23 can be used for managing and prioritising traffic transmission across the factory network  
 24 according to their QoS requirements. While these mechanisms work well for periodic traffic types  
 25 with constant bit rate, their performance and efficiency would degrade significantly when  
 26 processing multiple sporadic data streams. This is because the 802 TSN standards mechanism are  
 27 designed for periodic traffic types with maximum bandwidth, such as video or audio data streams,  
 28 for the transmission over a specified delivery time as indicated in Clause 34 in [7] One of the main  
 29 considerations within the factory network is the need for the provisioning of QoS for a variety of  
 30 machine to machine (M2M) data types generated from a variety of sensors, perhaps at the same

<sup>2</sup> <https://www.ffp-a.org/news/index.html>

1 ~~time, with different priority classes. These data types are periodic in nature and have relatively~~  
2 ~~short packet size.~~

3 ~~Some Advanced~~ factories have ~~typically~~ employed wireline networks using the Fieldbus protocol.  
4 Wireless ~~communications-communications~~ have not been used extensively in factories, mainly  
5 because of concerns regarding their ~~stability and~~ reliability. Technology developments as well as  
6 standardization are keys to success for wireless utilization. If these efforts are proven successful,  
7 wireless use for IoT connectivity in factory can increase the connectivity of mobile or moving  
8 devices and units which cannot be connected to a wired network because of technology and  
9 topology constrains. Wireless communication helps to locate people and things moving around.  
10 It can also help to protect people ~~in-on~~ the factory floor and help them to identify critical situations  
11 more quickly while moving around.

12 When the factory network is extended over radio, some incompatibility in QoS provisioning  
13 between wired and wireless segments becomes apparent. One reason is dynamic variation in the  
14 available bandwidth over the radio segment due to wireless link quality variation resulting from  
15 non-deterministic noise/interference, distortion and fading.

16 Successful factory automation with a high degree of flexibility, dynamic management and control  
17 of end-to-end streams across mixed wired and wireless links ~~may be facilitated by requires~~ E2E  
18 coordination as illustrated in [Figure 2](#) above.

19 The impact of applying QoS ~~control~~ and ~~Time Synchronization~~ functions and protocols to  
20 heterogeneous ~~the~~ factory networks with mixed wired and wireless links is further analyzed ~~in~~  
21 ~~section “Gaps in existing IEEE 802 technologies”~~ below. First, however details of the environment  
22 and causes of radio impairments to the factory environment are presented ~~below~~.

## 23 **Coordination System for Factory Automation**

24 In current factories, various facilities and equipment with different standards, of different  
25 generations, and by different vendors, coexist in the same site. This heterogeneous factory  
26 environment is known as Brownfield [\[8\]](#) [\[4\]](#). Such networks must accommodate various wireless  
27 interfaces. IEC has produced coexistence guidelines for manually configuring wireless systems and  
28 networks for co-existence [\[9\]](#) [\[5\]](#) [\[10\]](#) [\[6\]](#). In order to overcome the variable environment for  
29 wireless communications (see “Radio Environment within Factories” below), coordination may  
30 prove superior to static configuration of network elements for co-existence. The same concept is  
31 also discussed ~~by IEC in~~ [\[11\]](#) [\[7\]](#).

## 32 **Radio Environment within Factories**

33 Some factory applications require reliable, low-latency, and low-jitter data transmission  
34 compared with applications in other ~~places-environments~~ like offices and homes. Furthermore,  
35 measurement results show that some factories are facing difficulties due to ~~(a)~~ severe  
36 environment for wireless communications, and/or ~~(b)~~ existence of uncoordinated and  
37 independent systems in the same space.

### 38 **(a) The Severe Environment for Wireless Communications**



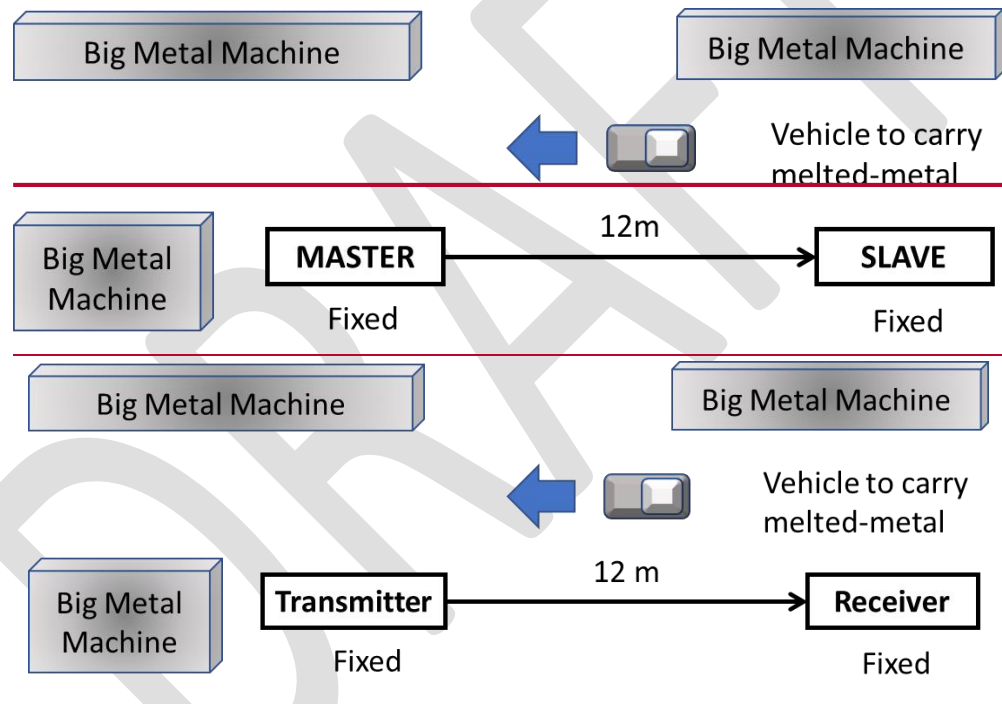
1 Two main sources of impairment to radio signals within the factory environment that cause  
2 unpredictable variations to channel capacity, namely:

- 3 1. Fluctuation of signal strength
- 4 2. Electromagnetic interference

5 Following are examples of such impairments observed within the factory environment.

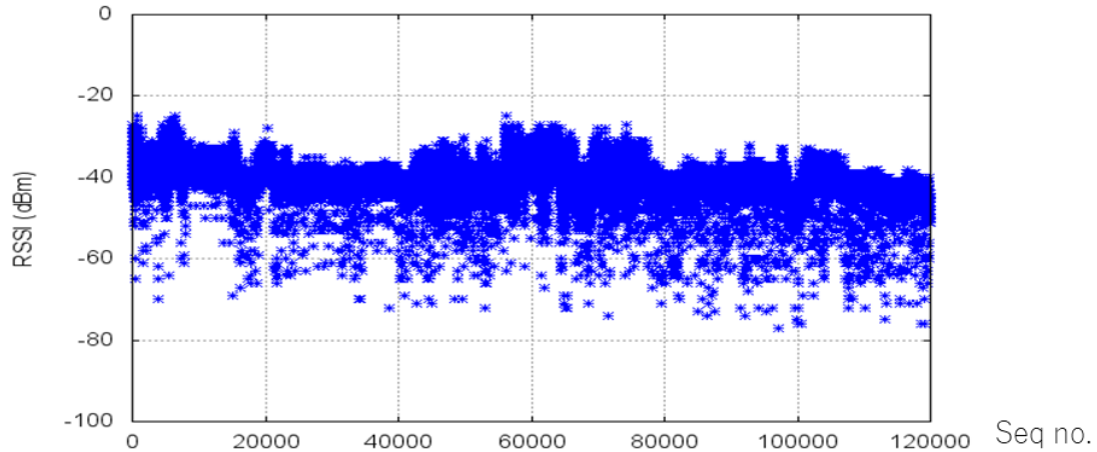
### 6 Example of Fluctuation of Signal Strength

7 Figure 3 illustrates an environment in which the measurements of Figure 4 were collected. ~~Master and slave transceivers were located and The line of sight between the transmitter and the receiver was not blocked by any obstacle during measurement there was no obstacle by a vehicle, human body and any other objects in the line between the master and slave transceivers during measurement.~~



14 **Figure 3 Layout in factory for which measurement of RSSI is recorded**

15 The observed Received Signal Strength Indicator (RSSI) measurement for this layout is shown in  
16 Figure 4 below. A packet with 54 Bytes was sent at each sequential (Seq) number with 10 msec  
17 separation at a data rate of 6 Mbit/s.



1

2

**Figure 4 RSSI Fluctuation in Factory**

3

This fluctuation in RSSI show in Figure 4 may be due to motions of materials, parts, products and carriers in closed space, with multi-path reflections-. Similar issues are reported as indicated in the NIST report on "Guide to Industrial Wireless Systems Deployments-" [12][8].

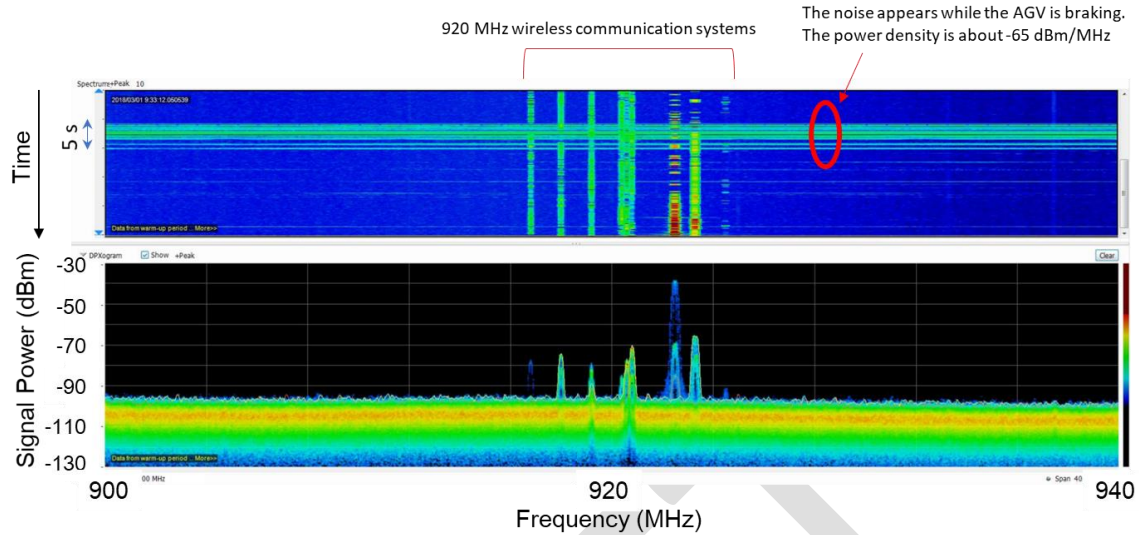
6

**Example of Noises:**

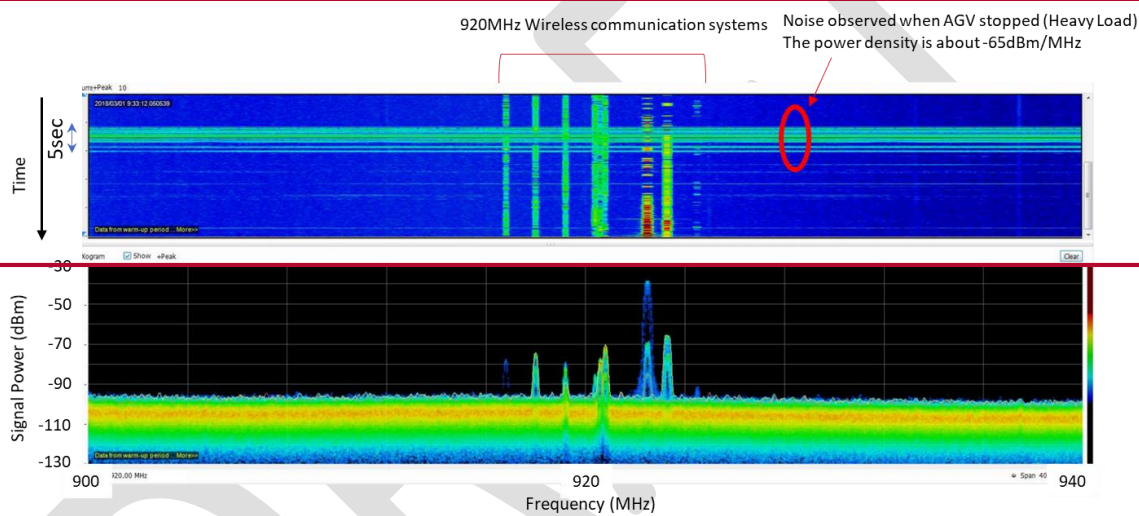
7

Measurements within the one factory environment indicate considerable noise signal within the 920\_MHz band. This is shown in Figure 5. The source of the noise signal has been confirmed as Automated Guided Vehicles (AGVs) carrying heavy load, as the noise appears while the AGV is breaking the noise disappears when the AGV stops.

11



1



2

3

**Figure 5 Measured noise spectral density ~~within 920MHz band~~**

4

The observed noise power was  $-65\text{ dBm/MHz}$ , ~~which were~~ above the receiver sensitivity for the 920 MHz wireless systems. ~~Under 1 GHz band, noise appears to cause problems for the communication with sensing systems using 920MHz band wireless communications. The source of the noise is attributed to manufacturing machines that are causing interference for the wireless communication systems.~~

6

9

**(b) Uncoordinated and Independent Systems**

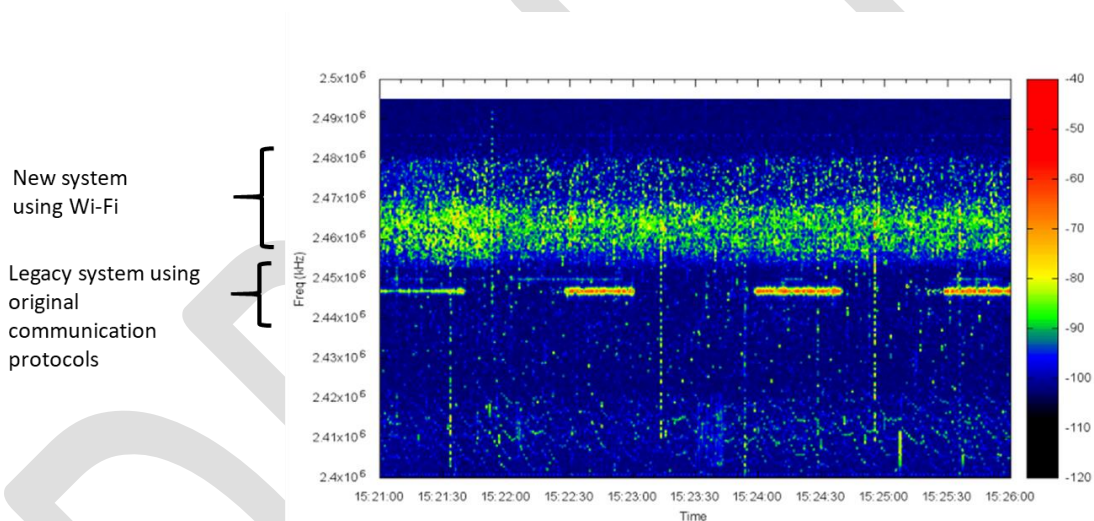
10

"The modernized factory environment leads to addition and reconfiguration of machines and equipment, much of which is outfitted with wireless network interfaces. This new environment brings about the requirement for coexistence of heterogeneous and legacy devices and systems. The progressive factory environment leads to addition and reconfiguration of machines and equipment in the factory and therefore to the requirement for coexistence of heterogeneous and legacy devices and systems."

15

1 When considering the coexistence of uncoordinated wireless systems, we observe the problem  
2 of interference between ~~the~~ legacy wireless communications used by some machinery in the  
3 factory with the newly introduced wireless systems ~~using Wi-Fi~~. In certain factories, many  
4 troubles ~~of manufacturing systems~~ appear after introducing the new wireless systems ~~using Wi-~~  
5 ~~Fi~~. The cause of this trouble is due to mutual interference between ~~manufacturing systems using~~  
6 the newly introduced wireless Wi-Fi system, and legacy systems using ~~original legacy~~  
7 communication protocols. Currently, the only way to avoid this problem is by assigning two  
8 separate frequencies for the two systems.

9 Figure 6 shows wireless signals operating in the 2.4 GHz band in an existing factory site where two  
10 systems coexist. ~~Although t~~he legacy system occupies one narrow Wi-Fi channel, ~~nevertheless,~~  
11 ~~there are but~~ only three Wi-Fi channels ~~that can be used without interference~~ are available.  
12 Because there is no common scheme for collision avoidance among different communication  
13 protocols, an independent channel should be assigned for each system to ensure stable factory  
14 operation. This limits the number of wireless systems, ~~with that~~ different communication  
15 protocols, which can operate in the same frequency band in a factory area.



16  
17 **Figure 6 Wireless signals with coexistence of different wireless technologies. The vertical**  
18 **and horizontal-axes show frequency (Hz) and time, and color shows signal strength (dBm)**  
19 **in a bar on the right hand side.**

## 21 Wireless applications and communication requirements

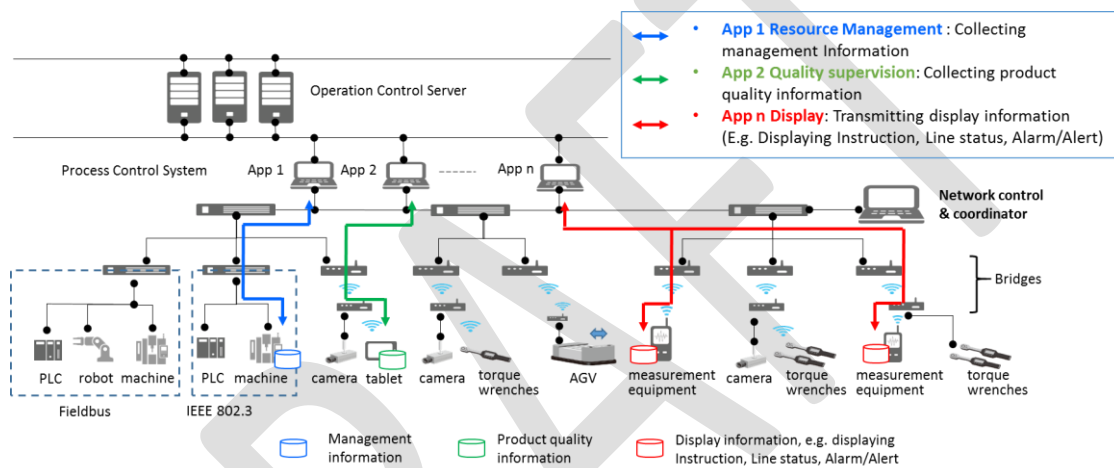
### 22 Scope of wireless applications in factory

23 The wireless applications considered in this clause illustrate ~~the use of~~ wireless systems that are  
24 used currently or in the near future ~~currently or soon to be used~~ in factories and related facilities.  
25 The applications correspond to wireless systems that are installed for specific purpose.

1 For example, wireless applications are highlighted ~~on~~in the factory network as shown in [Figure 7](#).  
 2 The color-coded lines indicate the data streams planned for specific purposes such as “Collecting  
 3 Management Information”. The wireless sub-networks consisting of multiple wireless  
 4 connections ~~have to be~~are deployed to support the information transmission and aggregation for  
 5 different applications.

6 The factory network ~~has to~~must be built, configured and managed ~~in a way that is able~~  
 7 the successful operation ~~in the wireless applications with wireless links~~. In some cases, ~~the a~~  
 8 critical application may demand a separate wireless segment setup due to special concerns.

9 The Section entitled “Factory Usage Scenarios” below considers ~~actual~~ factory sites with large  
 10 needs for wireless communication and describes usage scenarios ~~where in which~~ multiple wireless  
 11 applications coexist.



12  
 13 **Figure 7 Scope of wireless applications in factory**  
 14

15 **Wireless applications**

16 In a usage survey ~~in [13][9]~~ of wireless communication in factories, characteristics of various  
 17 applications were collected. These are classified according to their purposes, and organized by  
 18 their communication requirements. Collected wireless applications are listed in Table 1. These  
 19 were divided into six categories, (equipment control, quality supervision, factory resource  
 20 management, display, human safety, and others), and then subdivided into thirteen classifications  
 21 according to their corresponding purposes.

22 **Table 1 Wireless applications**

| Category          | Description   | Classification according to the purpose  |
|-------------------|---|--|
| Equipment Control | Sending commands to mobile vehicles, production equipment and receiving status information. | (1) Controlling, operating and commanding of production equipment, auxiliary equipment |

|                             |   |  |
|-----------------------------|---|--|
| Quality Supervision         | Collecting information related to products and states of machines during production   | (2) Checking that material is being produced with correct precision<br>(3) Checking that production is proceeding with correct procedure and status  |
| Factory Resource Management | Collecting information about whether production is proceeding under proper environmental conditions, and whether personnel and things <sup>3</sup> contributing to productivity enhancement are being managed appropriately | (4) Checking that the production environment (e.g. according to factors such as temperature, pressure, etc.) is being appropriately managed<br>(5) Monitoring movement of people and things<br>(6) Checking the status of equipment and checking the material, small equipment and tool stocks<br>(7) Monitoring the maintenance status of equipment during operation<br>(8) Appropriate recording of work and production status |
| Display                     | For workers, receiving necessary support information, for managers, monitoring the production process and production status   | (9) Providing appropriate work support, such as instructions and tracking information<br>(10) Visually display whether the process is proceeding without congestion or delay, production irregularities<br>(11) Visually display the production status, the production schedule, and any deviations or operational abnormalities   |
| Human Safety                | Collecting information about dangers to workers   | <del>(12)</del> Ensuring the safety of workers<br><del>(12)</del>  |
| Others                      | Communication infrastructure with non-specific purposes   | (13) Cases other than the above  |

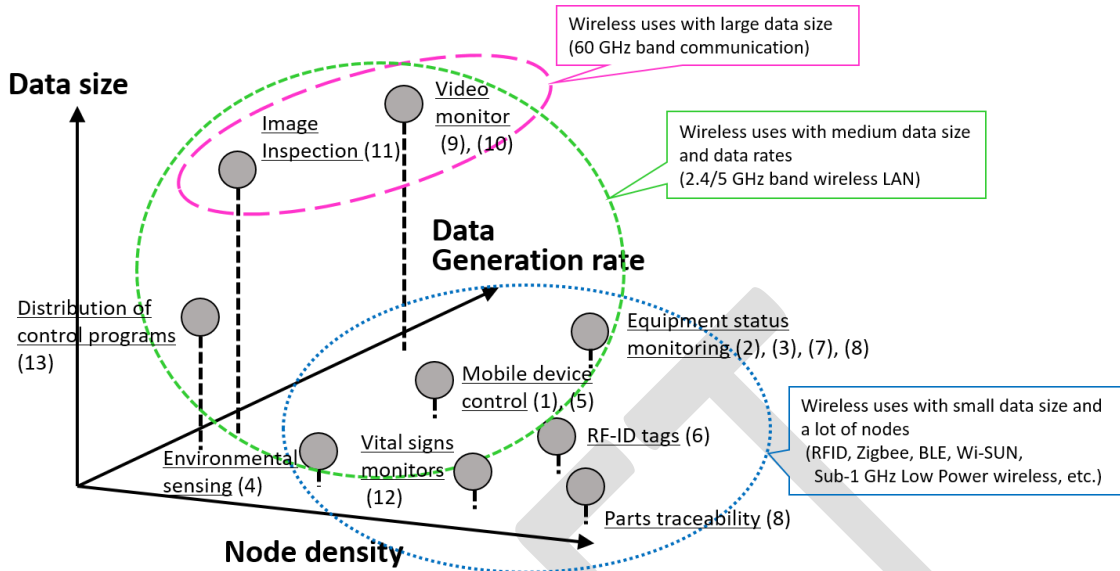
1

## 2 **Communication requirements**

3 **Figure 8** shows representative wireless applications, with corresponding classifications (1)-(13)  
4 from Table 1, and their wireless communication features. Values of data size, data generation  
5 rate, number of wireless nodes, and so forth depend on the required functions of the systems.  
6 ~~They~~ Wireless networks use different wireless frequency bands and wireless standards. High  
7 frequency bands such as 60 GHz band are expected to be effective for systems with relatively  
8 large data volume requirements (image inspection equipment, etc.). 5 GHz band and 2.4 GHz band  
9 networks are ~~being~~ used for systems with medium requirements of data sizes and data generation  
10 rate, such as distributing control programs and control of mobile equipment. Relatively low  
11 wireless frequency bands such as ~~Sub- below~~ 1 GHz are being used for applications with low power  
12 requirements (such as environmental sensing).<sup>4</sup>

<sup>3</sup> Physical objects such as materials and equipment related to production are called “things”

<sup>4</sup> Lower-frequency radio waves propagate better than higher-frequency one. ~~It achieves~~ This allows a better range and lower transmitting power, resulting in low power consumption. Environmental sensing ~~which~~



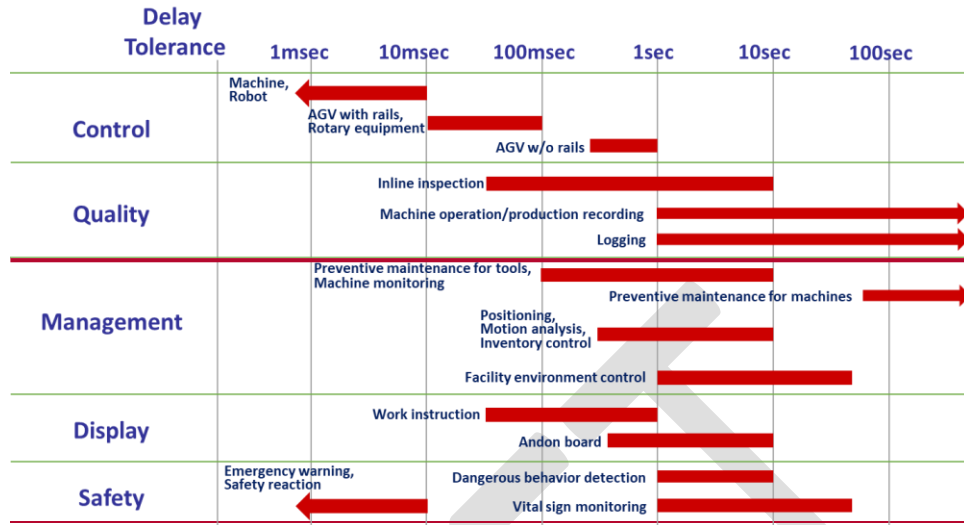
1

2 **Figure 8 Representative wireless applications with corresponding classifications (1)-(13)**  
 3 **from Table 1 and their wireless communication features**

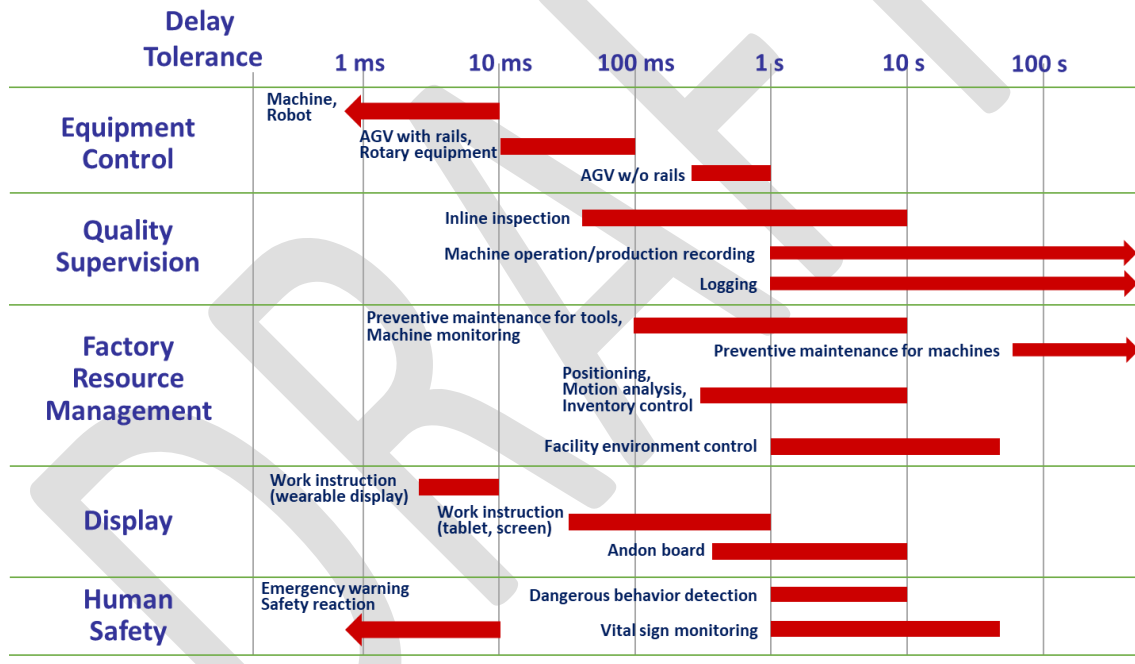
4 Figure 9 shows the permissible delay for representative wireless applications as in [13][9] and  
 5 [16][11]. ~~There are for some~~ wireless applications, such as robot control and urgent  
 6 announcements, ~~for which~~ the urgency and accuracy of information arrival timing requires less  
 7 than one millisecond latency. On the other hand, particularly in the categories of quality (inline  
 8 inspection, etc.) and management (preventive maintenance, etc.), there are many wireless  
 9 applications that tolerate latencies larger than ~~hundred~~ 100 milliseconds.

that requires long life battery operation is a good example of low power applications. Lower-frequency  
 bands ~~like Sub below~~ 1 GHz have ~~yes~~ become ~~de facto standard typical~~ for such applications [14][10][15].

1



2



3

Figure 9 Permissible delay of representative wireless applications

4

### Details of wireless application and communication requirements

5

Communication requirements for the thirteen classifications of wireless applications are organized in Tables 2 to 14. Each table contains further detailed purpose of the wireless application, corresponding information, and the communication requirements of transmitted data size, communication rate, delivery time tolerance, and Node density<sup>5</sup>. These attributes are

8

<sup>5</sup> Node density: number of terminals per 20\_m x 20\_m. This area dimension is based on the structure in a typical factory in which pillars are separated by 20\_m.



1 based on ~~observation~~ a survey involving for a number of samples within ~~the many~~ factories  
 2 surveyed<sup>6</sup>.

3 **Table 2 List of wireless applications and communication requirements for equipment**  
 4 **control**

5 (1) Controlling, operating and commanding of production equipment and auxiliary  
 6 equipment

| No. | Wireless application                 |                           | Communication requirements |                             |                         |              |
|-----|--------------------------------------|---------------------------|----------------------------|-----------------------------|-------------------------|--------------|
|     | Purpose                              | Corresponding Information | Transmit Data Size (bytes) | Communication Rate          | Delivery Time Tolerance | Node density |
| 1   | Control of liquid injection          | Water volume              | 64                         | Once per 1 min <del>-</del> | 100 ms <del>-</del>     | 1            |
| 2   | Operation of conveyor control switch | PLC                       | 16                         | 5 per <u>1 day</u>          | 100 ms <del>-</del>     | 5            |
| 3   | AGV control                          | Go signal, positioning    | 100                        | Once per 1 min <del>-</del> | 100 ms <del>-</del>     | 1 to 10      |
| 4   | Bottle filling                       | Fill valves               | 400                        | Once per <u>1 ms</u>        | 500 $\mu$ s             | 2            |
| 5   | Warehouse                            | Stacker crane positioning | 10                         | Once per 2 to 5 ms          | 1 ms                    | 1 to 20      |

7

8 **Table 3 List of wireless applications and communication requirements for Quality**  
 9 **Supervision -1**

10 (2) Checking that products are being produced with correct precision

| No. | Wireless application                         |  | Communication requirements |                                    |                         |               |
|-----|--|--|----------------------------|------------------------------------|-------------------------|---------------|
|     | Purpose                                      | Corresponding Information  | Data Size (bytes)          | Communication Rate                 | Delivery Time Tolerance | Node density  |
| 6   | Size inspection by line camera (line sensor) | Size measurements  | 30_K                       | Once per <u>1 sec</u> <del>-</del> | 5 s <del>-</del>        | <u>1 to 5</u> |
| 7   | Detect defect state                          | Defect information (video)                                       | 500                        | Once per 100 msec <del>-</del>     | 500 ms <del>-</del>     | <u>1 to 5</u> |
| 8   | Detect incorrect operation                   | Anomalous behavior due to adding impurities (e.g. Contamination) | 1_M                        | Once per <u>1 sec</u> <del>-</del> | 10 s                    | <u>1 to 5</u> |

<sup>6</sup> The survey in [13] was conducted in 2016 by collecting information from factories of foods, beverages, steels, pulp and paper mill, semiconductors, electrical equipment, electronics devices, communication devices, automotive, chemical plant, precision instruments, and metal processing. The survey included information from companies that provide devices and equipment with communication functions to factories. Additional information available on the internet was also included in the survey results.

1

2 **Table 4 List of wireless applications and communication requirements for Quality**  
3 **Supervision -2**

4 (3) Checking that manufacture is proceeding with correct procedure and status

| No . | Wireless application                  |  | Communication requirements |                             |                        |              |
|------|---------------------------------------|--|----------------------------|-----------------------------|------------------------|--------------|
|      | Purpose                               | Corresponding Information                            | Data Size (bytes)          | Communication Rate          | Arrival Time Tolerance | Node density |
| 9    | Sensing for managing air conditioning | Air stream to control temperature in different zones | 64                         | Once per <del>1 sec</del>   | 1 min <del>-</del>     | 1            |
| 10   | Monitoring of equipment               | State of tools, disposables                          | A few hundreds             | Once per <del>1 sec</del>   | 1 s <del>-</del>       | 2            |
| 11   | Counting number of wrench operations  | Pulses   | 64                         | Once per 1 min <del>-</del> | 100 ms <del>-</del>    | 10           |

5

6 **Table 5 List of wireless applications and communication requirements for Factory**  
7 **Resource Management -1**

8 (4) Checking that the factory environment is being correctly managed

| No . | Wireless application                  |                           | Communication requirements |                           |                         |              |
|------|---------------------------------------|---------------------------|----------------------------|---------------------------|-------------------------|--------------|
|      | Purpose                               | Corresponding Information | Transmit Data Size (bytes) | Communication Rate        | Delivery Time Tolerance | Node density |
| 12   | Managing clean room (booth)dust count | Dust count (particles)    | 32                         | Once per <del>1 min</del> | 5 s <del>-</del>        | 5            |
| 13   | Managing carbon dioxide concentration | CO2 concentration         | 16                         | Once per <del>1 min</del> | 5 s                     | 2            |
| 14   | Preventive maintenance                | Machine's temperature     | A few tens                 | Once per event            | 1 s                     | 2            |

9

10 **Table 6 List of wireless applications and communication requirements for Factory**  
11 **Resource Management -2**

12 (5) Monitoring movement of people and things

| No . | Wireless application |                           | Communication requirements |                            |  |              |
|------|----------------------|---------------------------|----------------------------|----------------------------|--|--------------|
|      | Purpose              | Corresponding Information | Transmit Data Size (bytes) | Communication Rate         | Delivery Time Tolerance                                | Node density |
| 15   | Movement analysis    | Wireless beacon           | A few tens                 | Twice per <del>1 sec</del> | A few <del>second</del> <del>sec</del><br><del>s</del> | 1 o 10       |

|    |  |  |                         |                            |      |    |
|----|--|--|-------------------------|----------------------------|------|----|
| 16 | Measuring location of people and things, e.g. radio beacon | Transmission time (phase), radio signal strength, etc. | A few tens of thousands | Once per <del>1 sec.</del> | 1 s- | 2  |
| 17 | Measuring location of products                             | Location of products during manufacture                | 200                     | Once per <del>1 sec.</del> | 1 s  | 20 |

1

2 **Table 7 List of wireless applications and communication requirements for Factory**  
3 **Resource Management -3**

4 (6) Checking the status of equipment and checking the material, small equipment and tool stocks

| No | Wireless application                 |                                     | Communication requirements |                                     |                         |              |
|----|--------------------------------------|-------------------------------------|----------------------------|-------------------------------------|-------------------------|--------------|
|    | Purpose                              | Corresponding Information           | Transmit Data Size (bytes) | Communication Rate                  | Delivery Time Tolerance | Node density |
| 18 | Racking assets (beacon transmission) | Information of equipment and things | 200                        | Once per <del>1 sec.</del>          | 1 s-                    | 20           |
| 19 | Tracking parts, stock                | RFID tag                            | 1_K                        | 1~10 times per 30 min <del>s.</del> | 100 ms                  | 3 to 30      |

5

6 **Table 8 List of wireless applications and communication requirements for Factory**  
7 **Resource Management -4**

8 (7) Monitoring the maintenance status of equipment during operation

| No | Wireless application               |                             | Communication requirements |  |   |              |
|----|------------------------------------|-----------------------------|----------------------------|--|---|--------------|
|    | Purpose                            | Corresponding Information   | Transmit Data Size (bytes) | Communication Rate                                     | Delivery Time Tolerance                             | Node density |
| 20 | Managing facilities                | Activity of PLC             | 4_K                        | Once per <del>1 sec.</del><br>~ once per <u>1 min.</u> | <del>1 s</del> One ~ few tens of <del>1 secs.</del> | 1 to 10      |
| 21 | Measuring energy                   | Energy, current fluctuation | 64                         | Once per <u>1 min.</u>                                 | 1 min   | 1            |
| 22 | Monitoring revolving warning light | Defect information          | 100                        | <del>A few times per 1 hour</del>                      | 1 s   | 25           |

9

10 **Table 9 List of wireless applications and communication requirements for Factory**  
11 **Resource Management -5**

12 (8) Appropriate recording of work and production status

| No | Wireless application |                           | Communication requirements |                        |                         |              |
|----|----------------------|---------------------------|----------------------------|------------------------|-------------------------|--------------|
|    | Purpose              | Corresponding Information | Transmit Data Size (bytes) | Communication Rate     | Delivery Time Tolerance | Node density |
| 23 | Work record          | Text data                 | 100                        | Once per <u>1 min.</u> | 1 s                     | 9            |

|    |                                |                        |       |   |                |         |
|----|--------------------------------|------------------------|-------|---|----------------|---------|
| 24 | Work proof                     | Certification data     | 1_K   | Once per <del>3_hours</del>               | 10 s           | 9       |
| 25 | Checking completion of process | Image, torque waveform | 100_K | Once per 1 <del>sec</del> (up to -1 min-) | 200 m <u>s</u> | 1 to 14 |
| 26 |                                | OK, NG                 | 100   | Once per 1 <del>sec</del> (up to -1 min-) | 200 ms         | 1 to 14 |

1

2 **Table 10 List of wireless applications and communication requirements for Display -1**

3 (9) Providing appropriate work support, such as instructions and tracking information

| No | Wireless application                |                           | Communication requirements |                                       |                         |              |
|----|-------------------------------------|---------------------------|----------------------------|---------------------------------------|-------------------------|--------------|
|    | Purpose                             | Corresponding Information | Transmit Data Size (bytes) | Communication Rate                    | Delivery Time Tolerance | Node density |
| 27 | Work commands (wearable device)     | Image                     | 600                        | Once per 10 <del>secs. ~ 1 min-</del> | 1~10 s                  | 10 to 20     |
| 28 | View work manual                    | Text data                 | 100                        | Once per <del>1 hour</del>            | 10 s                    | 9            |
| 29 | display information (image display) | image (video/still image) | 5_M                        | once per 10 <del>secs. ~ 1 min-</del> | <u>A few seconds</u>    | 1 to 5       |

4

5 **Table 11 List of wireless applications and communication requirements for Display -2**

6 (10) Visually display whether the process is proceeding without congestion or delay  
7 production irregularities

| No | Wireless application               |                                      | Communication requirements                     |                                       |                                  |              |
|----|------------------------------------|--------------------------------------|--|---------------------------------------|----------------------------------|--------------|
|    | Purpose                            | Corresponding Information            | Transmit Data Size (bytes)                     | Communication Rate                    | Delivery Time Tolerance          | Node density |
| 30 | Managing congestion                | Counter (number or remaining number) | <del>A Ffew</del> bytes                        | Once per 10 <del>secs. ~ 1 min-</del> | <del>A Ffew</del> <u>seconds</u> | 1 to 10      |
| 31 | Managing operation activity        | Activity of PLC                      | 128  | Once per <del>1 hour</del>            | 100 ms                           | 2            |
| 32 | Displaying revolving warning light | ON/OFF                               | <del>FA</del> few bytes (a few contact points) | Once per 10 <del>secs. ~ 1 min-</del> | 0.5~2.5 s                        | 30           |

8

9 **Table 12 List of wireless applications and communication requirements for Display -3**

10 (11) Visually display the production status, the production schedule, and any deviations or  
11 operational abnormalities

| No | Wireless application        |                           | Communication requirements |                                      |                         |              |
|----|-----------------------------|---------------------------|----------------------------|--------------------------------------|-------------------------|--------------|
|    | Purpose                     | Corresponding Information | Transmit Data Size (bytes) | Communication Rate                   | Delivery Time Tolerance | Node density |
| 33 | Managing operation activity | Image                     | 6_K                        | 30 per <del>1_s_ee</del> (30fps)     | 500 ms                  | 1            |
| 34 | Supporting workers          | PLC                       | 200                        | Once per 10 <del>secs_~ 1_min_</del> | 500 ms                  | 5            |
| 35 | Supporting maintenance      | Image, audio              | 200                        | Once per 100 <del>m_ssec_</del>      | 500 ms                  | 1            |

1

2

**Table 13 List of wireless applications and communication requirements for Human safety**

3

(12) Ensuring the safety of worker

| No | Wireless application                           |   | Communication requirements |                                       |                         |              |
|----|--|---|----------------------------|---------------------------------------|-------------------------|--------------|
|    | Purpose  | Corresponding Information                       | Transmit Data Size (bytes) | Communication Rate                    | Delivery Time Tolerance | Node density |
| 36 | Detecting dangerous operation                  | Image   | 6_K                        | 10 per <del>1_s</del> (10fps)         | 1 s_                    | 1            |
| 37 | Collecting bio info for managing worker safety | Vitals information (wearable)                   | 100                        | Once per 10 s                         | 1 s                     | 9            |
| 38 |  | Vitals information (fixed, relay)               | 200                        | Once per 1 min                        | 5 s                     | 20           |
| 39 |  | Gait  | About 100K                 | ~10 per <del>1_s</del> (1 fps~10_fps) | 1 <del>min</del>        | 10 to 20     |
| 40 | Detect entry to forbidden area                 | Body temperature, infrared                      | 2                          | When event occurs                     | 1 s                     | 1            |
| 41 | detect entry in the proximity of a machine     | Position of human (via connected wireless unit) | 10 - 30                    | 100 to 1000 per <del>1_s</del>        | 2 to 20 ms              | 1 to 50      |

4

5

**Table 14 List of wireless applications and communication requirements for others**

6

(13)Cases other than above

| No | Wireless application               |                           | Communication requirements                             |                    |  |              |
|----|------------------------------------|---------------------------|--|--------------------|--|--------------|
|    | Purpose                            | Corresponding Information | Transmit Data Size (bytes)                             | Communication Rate | Delivery Time Tolerance                          | Node density |
| 42 | Sending data to robot teaching box | Coordinates               | Few hundred <del>thousands</del> <del>kilo</del> bytes | Twice per year     | Less than 500 <del>msec_</del> (safety standard) | 10           |

|    |                                  |                         |      |                     |       |   |
|----|----------------------------------|-------------------------|------|---------------------|-------|---|
| 43 | Relay of images moving           | Video                   | 20_K | 30 per 1_s          | 20 ms | 5 |
| 44 | Techniques, knowhow from experts | Video, torque waveforms | 24_K | 60 per 1_s (60 fps) | None  | 1 |

1

## 2 **Factory Usage scenarios**

3 The usage scenario represents a complete manufacturing process that utilize a number of factory  
4 applications to achieve a deliverable product. Examples of factor usage scenarios includes:

- 5 - Metal processing site
- 6 - Mechanical assembly site
- 7 - Elevated and high temperature work site
- 8 - Logistics warehouse site

9 ~~As follows we give detail description of these~~Below, we describe example factory usage scenarios  
10 and their collective applications used, ~~to within each of these manufacturing scenarios.~~

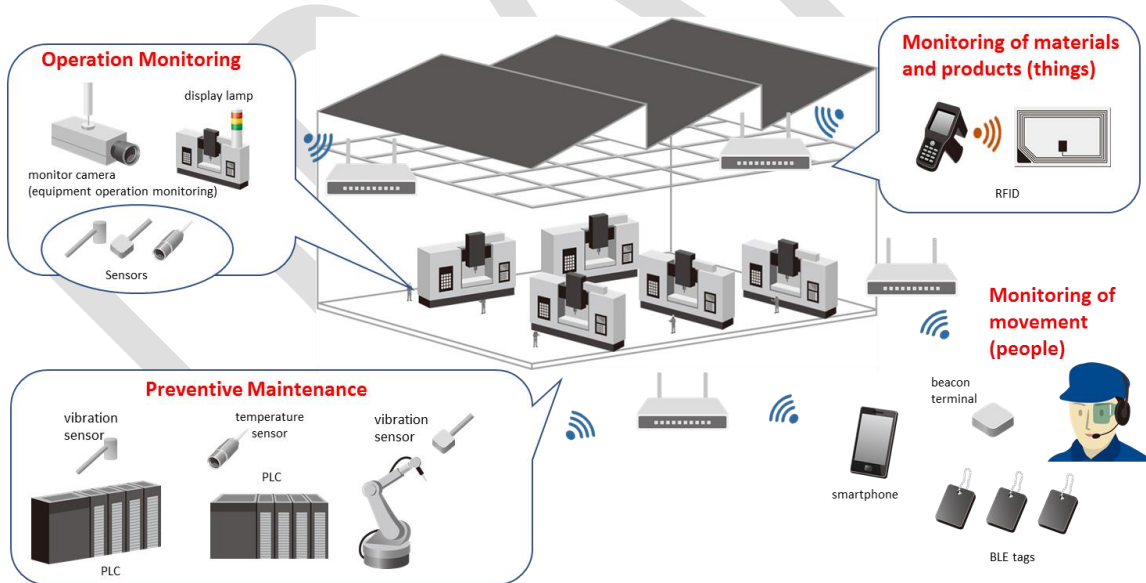
### 11 **Usage scenarios example: Metal processing site**

12 An illustration depicting a wireless usage scene at a metal working site is shown in [Figure 10](#). A  
13 building has a row of machine tools, and materials and products (things) are managed in a certain  
14 area of the building. Workers are at locations within the building as needed to operate the  
15 machines. In the case of operation monitoring and preventive maintenance, sensors may be  
16 attached to machines. As machine tools may be used for twenty to thirty years, there may be  
17 many old machines, with sensors attached after installation. Communication is necessary to  
18 collect information from sensors, but if ceilings are high, installing wiring requires high site work,  
19 making the cost of wiring expensive. The cost and long work times required by rewiring work  
20 when machines are relocated make wireless communication desirable. In the case of  
21 management of objects and analysis of worker movement, the subjects move, so the use of  
22 wireless communication is a necessity.

23 In the case of operation monitoring, monitor cameras and sensors are installed on machines to  
24 monitor the operation status of the machines. For wireless operation, wired LAN to wireless LAN  
25 media converters are installed on wired LAN ports. On machines without wired LAN ports,  
26 adaptors may be connected for wireless networking. A wireless network is formed between the  
27 machines and a wireless access point, and when an intermittently operated machine is switched  
28 on, a link with a wireless access point is established automatically without human intervention.  
29 As the wireless interference conditions change with the ON/OFF of wireless devices operating in  
30 coordination with the intermittent operation start and stop of nearby machines, it is necessary  
31 for the wireless network to have flexibility, such as monitoring the radio environment and  
32 switching the used frequency channel. Using this network, time series data such as vibration and  
33 torque waveforms acquired by tools and sensors inside machines during operation are sent to a  
34 server. Using the acquired data on the server, analysis software detects anomalies or anomaly  
35 precursors, and informs a manager. According to requirements such as the number of devices,  
36 transmitted data volume, and necessity of real time response, the data is transmitted by an  
37 appropriate wireless network such as wireless LAN, Bluetooth, or Zigbee.

1 In the case of preventive maintenance, various sensors are installed on machine tools. The sensors  
 2 and wireless communication device are implemented on a single terminal, and terminals may  
 3 execute primary processing before sending, or the gateway may execute primary processing on  
 4 data collected from sensors via a wireless network. When sensors and wireless device are  
 5 implemented on a single terminal, the terminal may aggregate data received from other terminals  
 6 within radio range and attach it to its own data when it transmits, to reduce the number of  
 7 transmissions. It may be necessary to sample or compress the data to reduce the volume of data  
 8 transmitted. Also, data may be normally recorded at the terminal, but limited under certain  
 9 conditions in order to reduce the data volume.

10 In the case of management of objects and movement of workers, wireless communications such  
 11 as Bluetooth Low Energy (BLE) are used to monitor the locations of people and things. A wireless  
 12 location monitoring system uses tags which periodically transmit beacons, and gateways which  
 13 receive the beacons. Multiple gateways are placed in the monitor area and tags are attached to  
 14 each person or thing to be monitored. Beacons transmitted by a tag are received by multiple  
 15 gateways and the received signal strengths are used determine the location of the tag. By  
 16 obtaining acceleration information as well as tag ID, the accuracy of location information can be  
 17 increased. Wireless communication is also used when an operator remotely operates a robot with  
 18 a terminal called a teaching box. The operator moves around the robot to visually check the  
 19 position of the robot and its relation with the object being processed. The movement of the  
 20 operator is only around the robot and not over a wide area, but it is important that the response  
 21 of the wireless communications is fast. In order to ensure safety, commands triggered by an  
 22 emergency stop switch need to be transmitted immediately and reliably.



23  
 24 **Figure 10 Usage scene: Metal working site**  
 25

26 **Usage scenarios example: Mechanical assembly site**

27 A wireless usage scene at a mechanical assembly site is shown in [Figure 11](#) as an example in  
 28 automotive plant. In a mechanical assembly plant, the benefit of wireless communications is  
 29 expected where there is management of building systems for collection and analysis of data for

1 quality management and traceability, and management of operations, such as Automated Guided  
2 Vehicles (AGV) for transport of components.

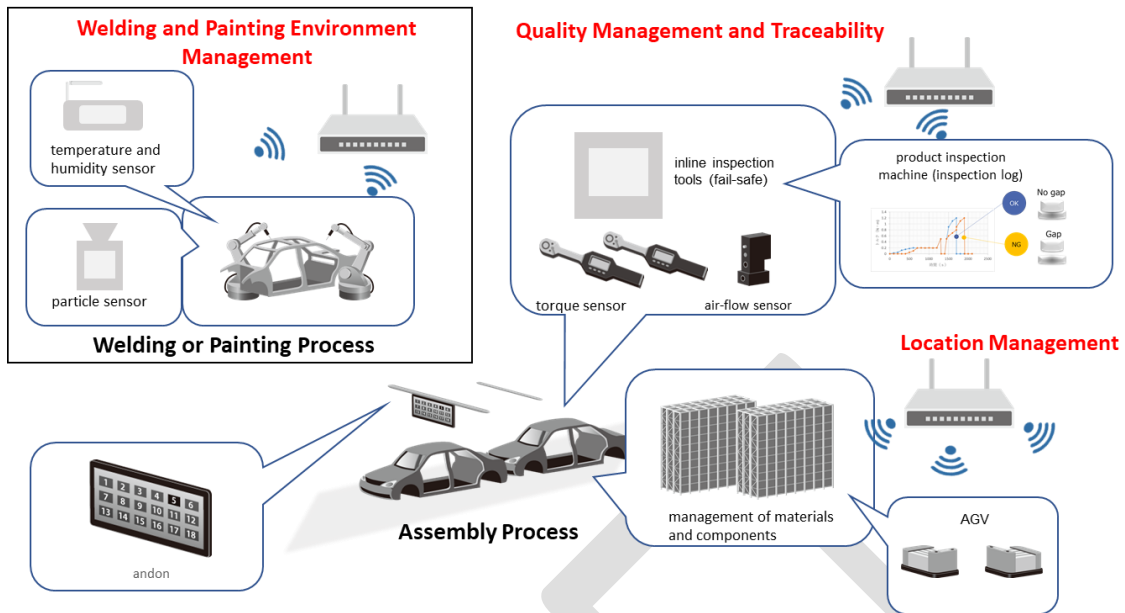
3 Wireless communication is used to send data to servers - inspection data from large numbers of  
4 workbenches, operation sequences in Programmable Logic Controllers (PLC) used for machine  
5 control, error information and environmental information. Also, work tools such as torque-  
6 wrenches, acquire and send data to servers such as the number of wrench operations and the  
7 success of the operations, and even time series data such as vibration and torque waveforms. As  
8 ISO 9001 specifies the mandatory recording of inspection data, it requires the reliable collection  
9 of data, although strict requirements are not imposed on communication latency. Hence when  
10 transmitting data, it is necessary to check radio usage in the neighborhood, and use available  
11 frequency bands and time slots (transmission times) according to the requirements such as  
12 number of machines, transmitted data volume and necessity of real-time response.

13 In the case of production management display (such as an “Andon” display board), in coordination  
14 with the above information, wireless communication is used to send data for real-time display of  
15 production status information, such as production schedule, production progress and production  
16 line operation status.

17 In the case of AGV with autonomous driving ability, the AGV itself will be able to control its current  
18 position and path. Each AGV will be sent a command “go from position A to position B” from a  
19 parent device (fixed device) and the AGV will move accordingly. As an AGV may move over a wide  
20 area in a factory, it is possible that in some locations the quality of wireless communication will  
21 degrade due to physical obstruction by facilities and manufacturing machine tools. Hence, it is  
22 necessary to consider the radio propagation environment when deciding where to place wireless  
23 access points and to consider the use of multi-hop networks. The number of mobile vehicles used  
24 in factories is continuing to increase, and the related issues of the radio environment will require  
25 more consideration in the future.

26 In a modern automotive plant, the welding or painting process is usually located adjacent to the  
27 mechanical assembly. As such, IoT devices such as temperature, humidity and particle sensors are  
28 used for environmental monitoring in places such as paint-shops or clean-booths as shown in  
29 Figure 13. Wireless communication is used for collecting sensor information remotely at any time  
30 from outside the rooms where the sensors are installed without requiring reconstruction work.  
31 The sensors transmit collected environmental information to an upper layer server at periodic  
32 time intervals. It is required that no data loss occurs. As such, communication routes can be  
33 checked when necessary at times of trouble, and relay devices can be installed where radio signal  
34 reception is weak without complex expert knowhow.





1

2

3

**Figure 11 Usage scene example: Mechanical assembly site (automotive plant)**

4

### Usage scenarios example: Elevated and high temperature work site

5

[Figure 12](#) shows an illustration of a wireless communication scene in an elevated and high temperature work site. In production sites such as chemical plants and steel plants, there are intrinsic dangers due to collisions and falls, and extreme environments with high temperatures and high humidity. Monitoring each worker's location and situation from vitals sensors and visual images will be an important application. Workers move about, so it is necessary to collect data using wireless communication. It is assumed that production facilities will be used for many years, so it is necessary to collect information about facility operation and monitor facility operation from the point of view of preventive maintenance. In regard to collecting information from existing facilities, the use of wireless systems that can be easily added are promising for monitoring facility operation using cameras and indicator lights.

15

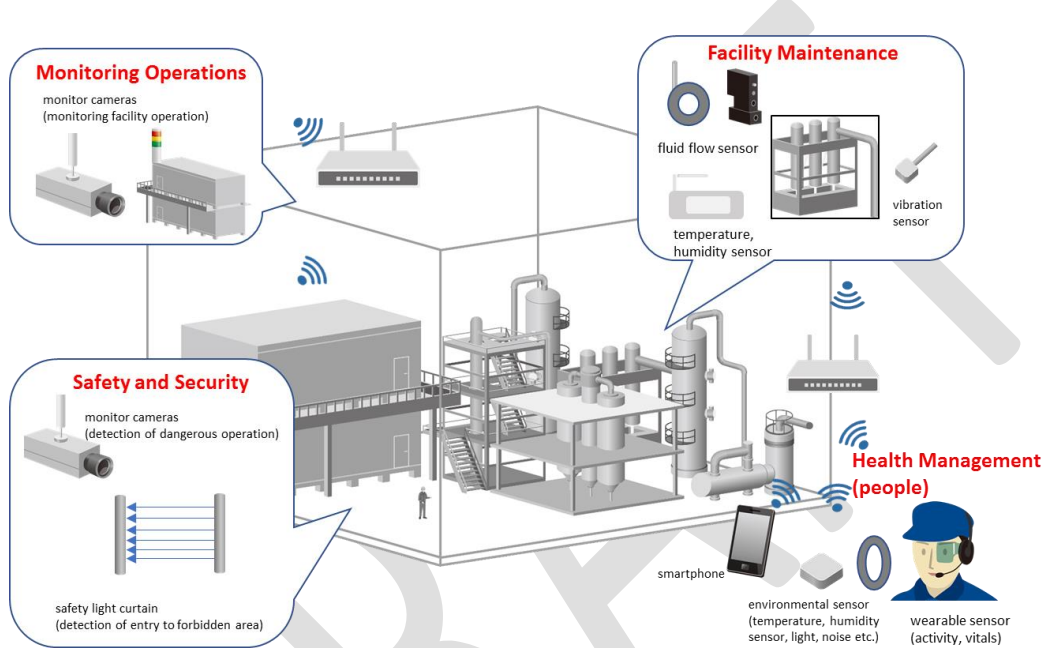
In a production site with elevated or high temperature work places, such as a drying furnace or a blast furnace, wireless communication is used to manage the safety of workers, by collecting workers' vitals sensor information (pulse, activity, body temperature, room temperature, posture for fall detection, etc.) and environmental information (temperature and humidity, pressure, dew point, etc.), and remotely monitoring the situation at the production site using cameras etc. In such cases, wireless communications, such as multi-hop networks with wireless LAN / 920 MHz communication, are used to collect data. Using sensors that detect entry into forbidden areas, combined with BLE beacons, it is possible to monitor the location of workers and warn of entry into dangerous areas. Wireless communications are basically used to transmit position information and vital information of each worker, but it is also possible to send alerts to workers and managers when an abnormal situation arises. Vitals sensors should be of types that do not interfere with work, such as wristwatch type, pendant type, or breast-pocket type.

27

The communication terminals in a production site may form a wireless multi-hop network, and upload sensor data to a cloud service or server (where the data is finally collected) via a gateway.

28

1 The uploaded data is used to monitor the worker's status. For example, in the case of a system  
 2 with a path from a sensor attached to a worker via a gateway to a server, wireless communication  
 3 from the sensor to the gateway might use 920\_MHz band communication, wireless LAN, or  
 4 Bluetooth. Communication from gateway to server will require connection via 3G/LTE or wired  
 5 LAN. When the server is far from the gateway, and it is necessary to have a wireless connection  
 6 (such as when wiring is not possible) a wireless mesh using wireless LAN, or a point-to-point 60  
 7 GHz frequency band system may be used as a backbone. In this case, interference between the  
 8 wireless backbone and the communication between sensors and gateway must be considered.



9  
 10 **Figure 12 Usage scene example: Elevated and high temperature work site**  
 11

12 **Usage scenarios example: Logistics warehouse site**

13 In a logistics warehouse<sup>7</sup>, as shown in [Figure 13](#), three-dimensional automatic storage<sup>8</sup> is used to  
 14 increase spatial use efficiency. Operation of a three-dimensional automatic storage system  
 15 requires monitoring of storage operation, preventive maintenance of the stacking system,  
 16 management of automated guided vehicle (AGV) movement, and so on. A large scale warehouse  
 17 has multiple storage racks placed in a rows, each of over 30\_m height and 100\_m length, and  
 18 separated by a few meters or less.

19 The operational status of the warehouse is monitored in conjunction with the transport of storage  
 20 items in and out by a computer-controlled stacker-crane. When the stacker-crane makes an  
 21 emergency stop due to detecting a stacking fault, workers might have to climb up a high ladder,  
 22 tens of meters high, to manually check and repair the stack.

<sup>7</sup> A warehouse in which items are stored and managed in racks, and moved in and out automatically with computer control.

<sup>8</sup> Equipment for transporting in and out of a three-dimensional automatic storage system.

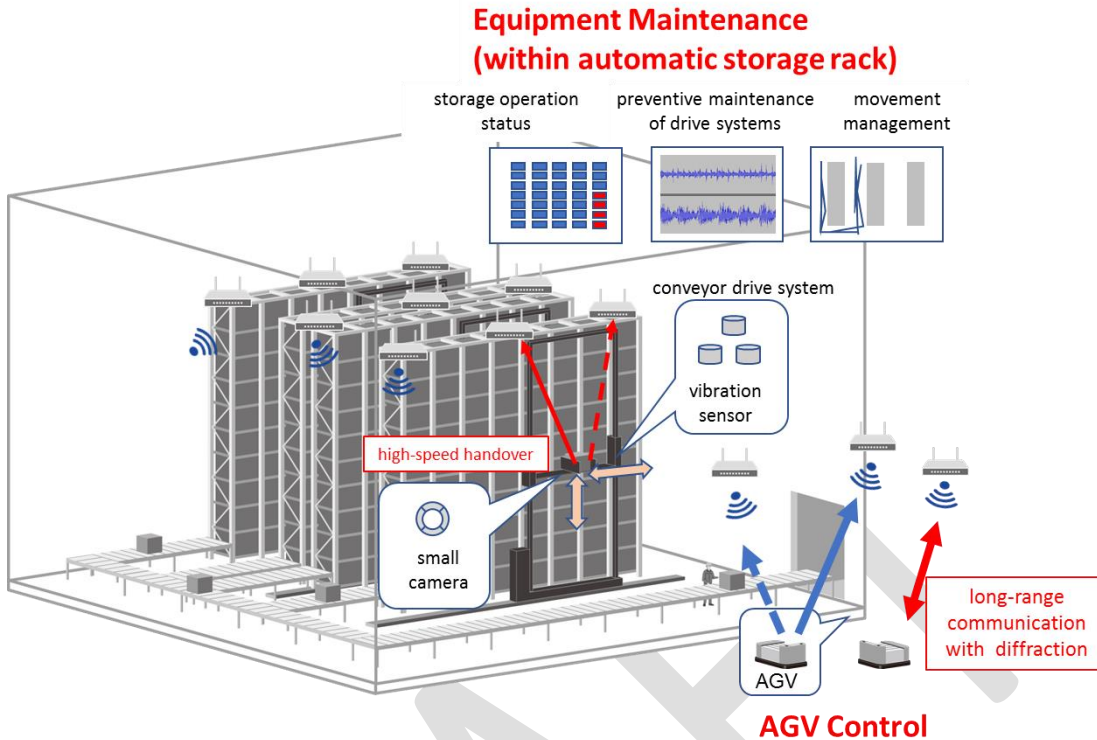
1 When the inspection and repair operation is in a high place, there is greater danger for the worker  
2 and operation delay time increases. Previously, workers had to spend time checking the storage  
3 even when there was actually no need to stop. Now cameras are used to remotely check the  
4 situation on the stacks and the stacker-crane to decide whether operation should be halted or  
5 continued, reducing the number of dangerous tasks of workers, and reducing the average time to  
6 recovering normal operation. However, in large-scale storage systems, the stacker-cranes move  
7 over large ranges, and wiring to cameras attached to stacker-cranes is difficult. Using wireless  
8 cameras eliminates the need for signal cables, and so the installation of wireless cameras in three-  
9 dimensional automatic storage systems is increasing. Information is sent from the wireless  
10 devices on the luggage platform of the stacker-crane to wireless access points (fixed stations)  
11 which are placed at one or both ends of the stacker-crane's floor rail.

12 The images sent from the camera could be video (for example, 30 frames-per-second VGA) or still  
13 images (for example, JPEG or PNG with VGA resolution). The speed of the luggage-platform could  
14 be as fast as 5 ~~meters-per-second~~m/s, and the wireless device should automatically select,  
15 connect to, and transmit data to the wireless access point with the best link quality. It should also  
16 avoid interference with wireless devices on other stacker-cranes which might be running on  
17 parallel racks separated by just a few meters.

18 In three-dimensional automated storage systems, higher speeds of stacker cranes and their  
19 continuous operation are required to increase the transport efficiency. Sensors are attached to  
20 the drive system that drives the vertical motion of the luggage-platform, and the drive system  
21 that drives horizontal motion of the crane along its rails. A wireless communication device relays  
22 the sensor data, and computer analysis and learning of the data is used for preventive  
23 maintenance of the drive systems.

24 In some cases, in order to increase the flexibility of the layout in the warehouse, the luggage  
25 carried out by a stacker-crane is transported to another storage or work place by a forklift or AGV.  
26 The magnetic tape that is used taped on the floor to guide the motion of a trackless AGV cannot  
27 carry data, so control information such as destination is sent by wireless communication. Also,  
28 forklifts and AGVs have devices for detecting their location, and location information is relayed  
29 by wireless communication. Location information collected from forklifts and AGVs is used to  
30 manage their operation, and methods are being developed to improve transport efficiency by  
31 coordinating their motion with stacker-cranes, allowing the selection of the AGV with the shortest  
32 travel distance, for example.

33 In regard to use of sensors for preventive maintenance on drive systems of stacker-cranes, and  
34 managing movement of forklifts and AGVs, in large scale factories, the range of motion may  
35 extend over large areas with various large structures such as three-dimensional storage racks, so  
36 the placement of wireless access points and the selection of wireless frequency band are  
37 important issues.



1  
2

Figure 13 Usage scene example: Logistics warehouse site

3 **Technological Enhancement of Networking**  
4 **for Flexible Factory IoT**

5 **Coexisting of wide variety of factory applications with different requirements**

6 According to Figure 9 and Tables 2~14 in Section “Wireless Applications and Communication Requirements”, examples of QoS tolerances in factory applications are summarized in Table 15.  
7 Table 15 shows that tolerance of latency is classified into small, medium or large, tolerance of bandwidth is classified into wide, medium or narrow, and tolerance of packet loss is classified into  
8 loss intolerant or loss-tolerant. It means that factory applications may require a large number of  
9 QoS classes more than the 8 classes specified in IEEE Std 802.1Q. To deal with a large number of  
10 QoS class requirements, defining usage of tag fields may be needed for precise and fine QoS  
11 control on L2.  
12  
13

14 In addition, there would be requirement to map priority from the 802.1 domain to the specific  
15 media (e.g. wireless link) and achieve the required performance.

16 **Table 15 Examples of QoS Tolerances in Factory Applications**

| Category of Wireless Applications | QoS Tolerances |          |       |                     |          |      |                 |               |
|-----------------------------------|----------------|----------|-------|---------------------|----------|------|-----------------|---------------|
|                                   | Latency (msec) |          |       | Bandwidth (kbit/ps) |          |      | Packet Loss     |               |
|                                   | <100           | 100~1000 | >1000 | >1000               | 100~1000 | <100 | loss-intolerant | loss-tolerant |
| Equipment Control                 | ✓              | ✓        |       |                     |          | ✓    | ✓               |               |

|                             |   |   |   |   |   |   |   |   |
|-----------------------------|---|---|---|---|---|---|---|---|
| Quality Supervision         | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |   |
| Factory Resource Management |   | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Display                     |   | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Human Safety                | ✓ |   | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Others                      |   | ✓ | ✓ | ✓ |   |   | ✓ | ✓ |

1

2 **Overview of the standard landscape for Flexible Factory IoT**

3 A list of relevant existing standards and standard projects are provided in Table 16.

4

5 **Table 16 Standards and Projects relevant to Flexible Factory Network**

| Working Group | Standard and Project                                   | Title  |
|---------------|--|--|
| 802.1         | <a href="#">IEEE Std 802.1Q-2018 Clause 35802.1Qat</a> | Stream Reservation Protocol (SRP)  |
|               | 802.1AS-REV  | Timing and Synchronization for Time-Sensitive Applications   |
|               | 802.1BA  | Audio Video Bridging (AVB) Systems   |
|               | 802.1Qcc   | Stream Reservation Protocol (SRP) Enhancements and Performance Improvements  |
|               | 802.1CB  | Frame Replication and Elimination for Reliability  |
|               | <a href="#">IEEE Std 802.1Q-2018 Clause 36802.1Qbb</a> | Priority-based Flow Control  |
|               | <a href="#">IEEE Std 802.1CF-2019P802.1CF/D3.1</a>     | <del>IEEE Recommended Practice for Network Reference Model and Functional Description of IEEE 802(R) Access Network</del><br><del>IEEE Recommended Practice for Network Reference Model and Functional Description of IEEE 802® Access Network</del> |
| 802.11        | <a href="#">IEC/IEEE 60802</a>                         | <a href="#">TSN Profile for Industrial Automation</a>  |
|               | 802.11aa   | MAC Enhancements for Robust Audio Video Streaming  |
|               | 802.11ak   | Enhancements for Transit Links Within Bridged Networks   |
|               | 802.11e  | Medium Access Control (MAC) Quality of Service Enhancements  |
|               | 802.11ae   | Prioritization of Management Frames  |

6

7 TSN defines standard L2 technology to provide deterministic capability on 802.1Q bridged  
8 networks. It guarantees end-to-end QoS for the real-time applications with bounded latency,  
9 minimized jitter, and high reliability. Industries like automotive, industrial and professional audio  
10 comprised by multiple network devices will benefit from deterministic connectivity and  
11 optimization over Ethernet wires.

1 Future industrial wireless communications will take advantage of this infrastructure. The  
2 wired/wireless integrated networks for future flexible factories IoT scenarios should be able to  
3 accommodate various applications with different end-to-end QoS requirements. These  
4 requirements can be guaranteed by closing the gaps within the following functions:

- 5 • End to end stream reservation in a wired/wireless integrated network
- 6 • Wireless link redundancy for reliability and jitter improvement
- 7 • Adaptation to rapid changes in wireless environments
- 8 • Coordination among the wireless transmissions in the unlicensed bands

## 9 Gaps analysis of existing standards and technologies for Flexible Factory network

### 10 End to end stream reservation in a wired/wireless integrated network

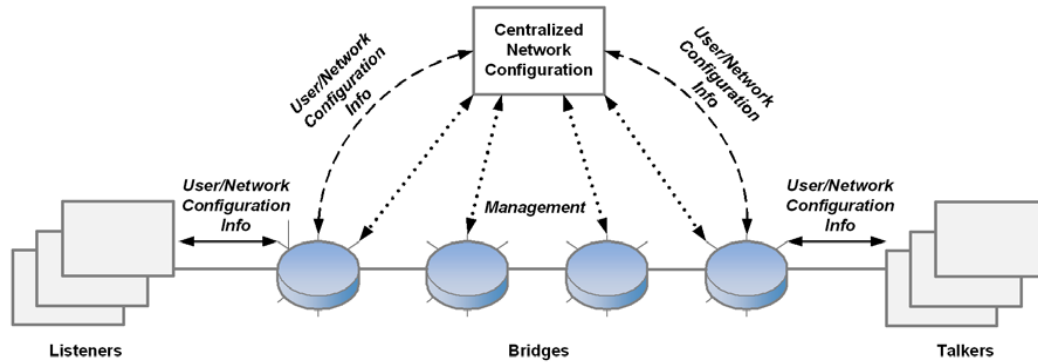
11 Streams are used to describe the data communication between end stations with strict time  
12 requirements. In 2010, the 'Audio/Video Bridging (predecessor of TSN) Task Group' (~~former TSN~~)  
13 standardized the Stream Reservation Protocol (SRP) as IEEE Std 802.1Q-2018 Clause 35~~IEEE~~  
14 802.1Qat, which was then incorporated in the mainline 802.1Q standard.

15 The protocol allows end stations to register their willingness to "Talk" or "Listen" to specific  
16 streams, and it propagates that information through the network to reserve resources for the  
17 streams. Network bridges between the end stations maintain bandwidth reservation records  
18 when a Talker and one or more Listeners register their intentions for the same stream over a  
19 network path with sufficient bandwidth and other resources. SRP utilizes three signaling protocols  
20 from IEEE Std 802.1Q-2018, MMRP (Clause 10.9), MVRP (Clause 11) and MSRP (Clause 35.1), to  
21 establish stream reservations across a bridged network. The network signaling for SRP to establish  
22 stream reservation is defined as the Multiple Stream Registration Protocol (MSRP), which is also  
23 standardized in 802.1Qat.

24 IEEE 802.11aa specifies a set of enhancements to the original 802.11 MAC QoS functions which  
25 enables the transportation of AV streams with robustness and reliability over wireless shared  
26 medium. It defines the interworking with bridge networks to facilitate end-to-end stream  
27 reservations when one or more 802.11 wireless links are in between Talker and Listener.

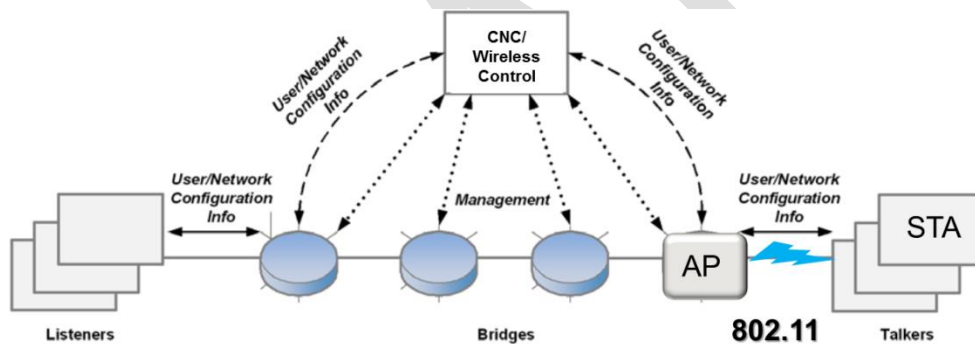
28 It is stated in Annex C.3 of 802.1Q that 'From the bandwidth reservation standpoint an IEEE 802.11  
29 BSS network is modeled as a Bridge'. As one of the essential advantages of SRP, it provides a  
30 single bandwidth reservation protocol across multiple media types of both wired and wireless.

31 The recent published standard IEEE 802.1Qcc specifies a set of large enhancements to SRP,  
32 introducing the concept of centralized configuration model with a centralized network controller  
33 (CNC). As shown in Figure 14, CNC is a new system level entity that may be capable of calculating  
34 the best possible solution for a set of predefined configuration ~~As shown in , CNC is a new system~~  
35 level entity that will calculate the best possible solution and configure the bridges to meet those  
36 QoS demands conveyed through the User Network Interfaces (UNI). Within UNI, the attributes  
37 about traffic specifics and maximum latency are shared with the CNC for proper stream  
38 management in an end-to-end perspective.



1  
2 **Figure 14 Centralized configuration bridge network**

3 Such a new paradigm can be much appreciated in the wired/wireless integrated networks in  
 4 flexible factories, as shown in [Figure 15](#). If partial network resources like bandwidth can't  
 5 temporarily meet the performance required by the traffic streams, the CNC will notify the user  
 6 and work out a solution with modified configuration to accommodate the QoS requirements of  
 7 the system. CNC kind of wireless controller for both bridges and 802.11 AP/STA will certainly be  
 8 helpful in the scenario to address the unstable wireless bandwidth and latency issues. By  
 9 managing all the traffic streams between all connections in the network, the robustness of the  
 10 stream reservation and the network efficiency will be both improved.



11  
12 **Figure 15 Centralized configuration heterogeneous network**

13  
14 **Wireless link redundancy for reliability and jitter improvement**

15 Beginning in around 2012, efforts began in the IEEE 802 TSN Task Group to specify seamless  
 16 redundancy in conjunction with TSN streams, particularly to address Layer 2 networks in industrial  
 17 control and automotive markets. Eventually, this led to the completion and publication of IEEE  
 18 Std 802.1CB-2017, specifying "Frame Replication and Elimination for Reliability" (FRER). IEEE  
 19 802.1CB provides specifications "for bridges and end systems that provide identification and  
 20 replication of packets for redundant transmission, identification of duplicate packets, and  
 21 elimination of duplicate packets." Essentially, packets are duplicated and transmitted along  
 22 differentiated paths; copies received at the destination, following the first, are discarded. The  
 23 purpose is "to increase the probability that a given packet will be delivered," and to do so in a

1 timely manner. FRER “can substantially reduce the probability of packet loss due to equipment  
2 failures.”<sup>9</sup>

3 FRER emphasizes improvement in loss, rather than latency. FRER is built upon earlier TSN  
4 standards and groups and, accordingly, presumes that frames are parts of a stream carried along  
5 a provisioned reservation. Accordingly, the latency of the reservation may be determined and  
6 presumed bounded; the bounds, however, depend on the reliability of the network along the  
7 reserved path. For some applications, this reliability limitation is insufficient. FRER can, in effect,  
8 provide instantaneous backup of each frame. This dramatically reduces the likelihood frame loss  
9 rate due to independent failure of identical equipment, roughly squaring it. For example, if each  
10 link experiences a frame loss rate of  $\epsilon$ , FRER would be expected to ~~have result in~~ a frame loss rate  
11 of  $\epsilon^2$ . The difference may be highly significant in practice.

12 FRER is specified to apply only to frames carried in TSN streams. Not all streams in a network need  
13 to be subject to FRER; it can be limited to mission-critical streams only.

14 The concept of frame duplication and duplicate elimination preceded TSN discussions toward IEEE  
15 Std 802.1CB. In fact, the concept was standardized as early as 2010 in IEC 62439-3:2010, “Parallel  
16 Redundancy Protocol (PRP) and High-availability Seamless Redundancy (HSR).” The standard  
17 supports the use of Ethernet in industrial applications. It is not based on TSN technologies and  
18 accordingly does not support the flexibility to sequence frames per stream. A number of industrial  
19 applications of PRP have followed.

20 The use of PRP wireless networks is not excluded and has been explicitly studied. This case is  
21 similar in principle but may be qualitatively different because the wireless link may be far more  
22 variable than the typical industrial wire link. As a result, a frame may be delayed significantly and  
23 unpredictably on a link without equipment failure. One implication is that, in the wireless  
24 environment, PRP may be more prominently used for jitter reduction rather than simply for frame  
25 loss.

26 Rentschler and Laukemann presented a study at the 2012 IEEE 17th International Conference on  
27 Emerging Technologies & Factory Automation (ETFA 2012) regarding PRP and wireless LAN  
28 (WLAN) [17][42]. Industrial applications were a key target. It noted that “wireless transmission is  
29 known to be error-prone and its error characteristics behave time-variable and non-deterministic.  
30 This labels wireless communication as not very well suited for industrial applications with tight  
31 reliability requirements, such as guaranteed maximum latency times for packet transmission.”  
32 The authors indicate that they consider “reliability, latency and jitter... as the most important  
33 criteria for industrial communication systems.”

34 Rentschler and Laukemann applied the standardized IEC PRP protocol to two parallel wireless  
35 LANs (WLANs) based on IEEE Std 802.11n; one of the two WLANs operated in the presence of  
36 interfering WLAN traffic. Regarding latency, the paper demonstrated that the minimum latency is  
37 attained without PRP, because the PRP processing adds delay. However, the maximum latency is  
38 attained with PRP, because PRP chooses the frame arriving first. PRP improved jitter (average

---

<sup>9</sup> IEEE Std 802.1CB includes the following note: “The term packet is often used in this document in places where the reader of IEEE 802 standards would expect the term frame. Where the standard specifically refers to the use of IEEE 802 services, the term frame is used. Where the standard refers to more generalized instances of connectionless services, the term packet is used.”



1 deviation of the mean latency) by about 40% in an example. The paper reported examples in  
2 which frame loss was around 0.02% per individual WLAN but in which frame errors were not  
3 observed using PRP due to the unlikelihood of simultaneous loss of both packets.

4 Rentschler and Laukemann study do not address the resource requirements necessary to  
5 implement PRP. In the wired case, whether PRP or FRER, the additional bandwidth resources to  
6 support redundancy may be supported by a cable and some switch ports. However, in the wireless  
7 case, the primary resource is a radio channel. As noted, one of the two available wireless channels  
8 in the Rentschler and Laukemann experiment was dedicated solely to the link. However, as  
9 discussed throughout this report, spectrum resources are limited in the factory environment. Each  
10 duplicated frame consumes twice the spectral resource of a single frame. If interference and  
11 channel availability are limiting factors, transmitting each packet in duplicate seems likely to be  
12 counter-productive. However, in some circumstances, such as for low-bandwidth mission-critical  
13 control messaging, duplicate wireless transmission might prove effective.

14 Another issue that needs to be considered regarding the application of PRP or FRER duplication  
15 in the wireless setting is the degree to which the pair of wireless channels is independent. For  
16 many realistic scenarios, such independence is a reasonable assumption in many wired networks.  
17 In the wireless case, the LAN elements may be physically separate, but the wireless environments  
18 may nevertheless be correlated. Operating the two links in different radio channels, or better yet  
19 different radio bands, can help to separate the interference conditions. However, even then, it is  
20 easy to imagine scenarios that would result in simultaneous degeneration of both links. One  
21 example might be a broadband noise source that affects both channels. Another example is that  
22 of large moving machinery, such as a moving truck discussed earlier in this report, which blocks  
23 the direct line-of-sight of two antennas.

24 A number of WLAN applications of PRP have since been discussed in the literature, and wireless  
25 industrial applications of PRP have been introduced in the market, primarily regarding WLAN.  
26 However, no wireless applications of IEEE Std 802.1CB have been identified in the literature.  
27 Perhaps the best explanation is that 802.1 TSN is rarely implemented in wireless networks and  
28 wireless traffic is rarely carried in TSN stream reservations, and therefore 802.1CB FRER is  
29 inapplicable. Should 802.1 TSN functionality, including TSN streams, become introduced into  
30 wireless networks, techniques like FRER could be considered. However, it appears that some  
31 additional complications could arise. For example, FRER relies on sequence numbering in which  
32 the number of bits required depends on the maximum possible path latency difference that needs  
33 to be accommodated. In the wireless case, given the expected difficulty in ascertaining a tight  
34 latency bound, that number could be difficult to assign or could be impractically large without  
35 improvements in network control and management.

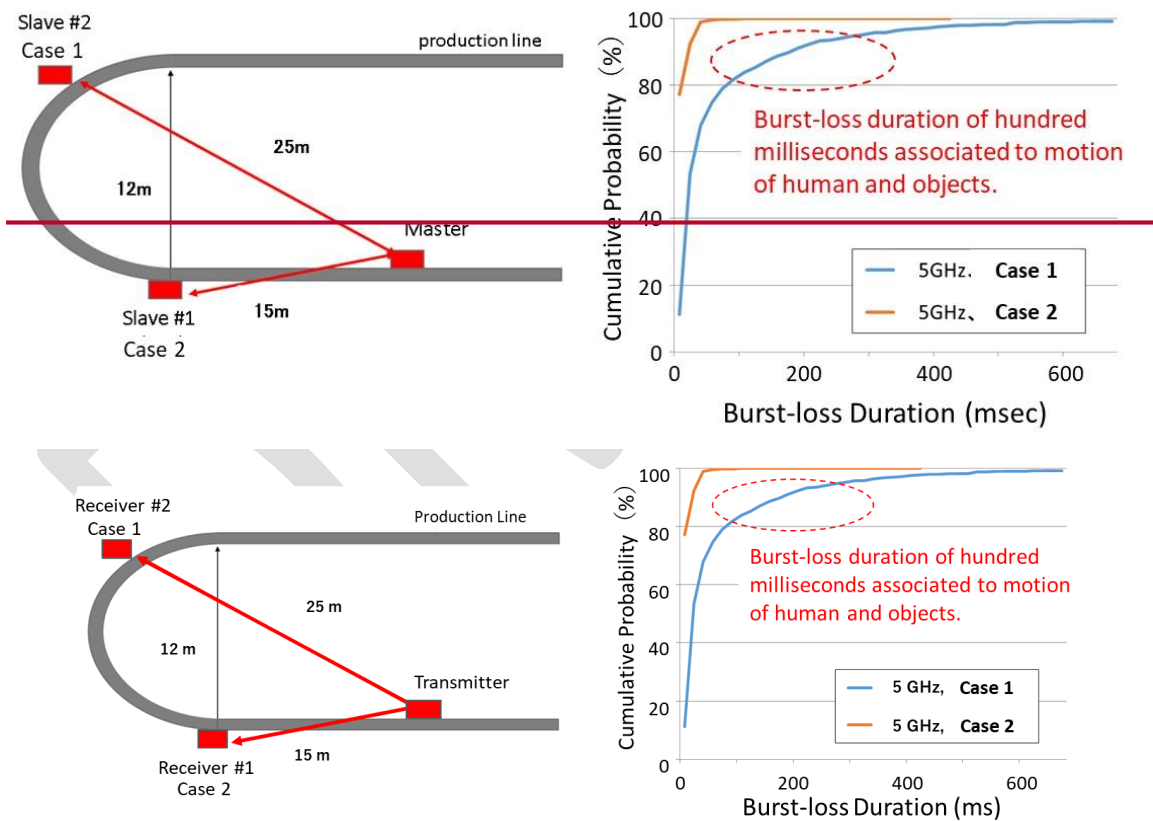
36 Concepts like FRER may find application in contributing to improved reliability and jitter in  
37 wireless factory networks. However, some of the challenges discussed will first need to be  
38 addressed and resolved.

### 39 **Adaptation to rapid changes in wireless environments**

40 Modern manufacturing process requires fast feedback to get immediate response after each  
41 action by worker in management and operation to increase high productivity and high quality of  
42 products, simultaneously, where human and machines tightly collaborate in high-mix and low-  
43 volume production. Permissible delay in feedback messages for most wireless applications in this

1 sense is ranging from 20 msec to 10 sec as shown in Figure 9. The lower boundary may be  
 2 determined by human reaction time [18][43]. For example, in an application in which an online  
 3 inspection occurs, an action by worker is checked by a system as to whether it is good or not.  
 4 He/she shall receive go/no-go signal from the system indicating to whether to proceed to the next  
 5 action or not. In the network accommodating factory, applications such as quality supervision,  
 6 factory resource management, display, and some of equipment control and safety, permissible  
 7 latencies within 100 msec or less for communications between a terminal and a management  
 8 system of the factory application are considered reasonable.

9 In a typical factory structure (or layout), there are many metallic objects that are moving in a  
 10 closed space, resulting in unforeseeable fluctuation in received radio signal indication (RSSI) due  
 11 to rapid change in propagation condition. An example of measurement in a metal casting site  
 12 showed RSSI changed by more than 20dB within a short time ranging from tens of milliseconds to  
 13 hundreds of milliseconds as discussed earlier in Figure 4. The bandwidth might decrease by one-  
 14 tenth in a case during RSSI dropped. Another example of measurement in a large machine  
 15 assembly site indicted burst-loss occurred for the duration of several hundred milliseconds as  
 16 shown in Figure 16.



17

18

19

**Figure 16 Burst-loss measurement in a large machine assembly site [19][44]**

20

21

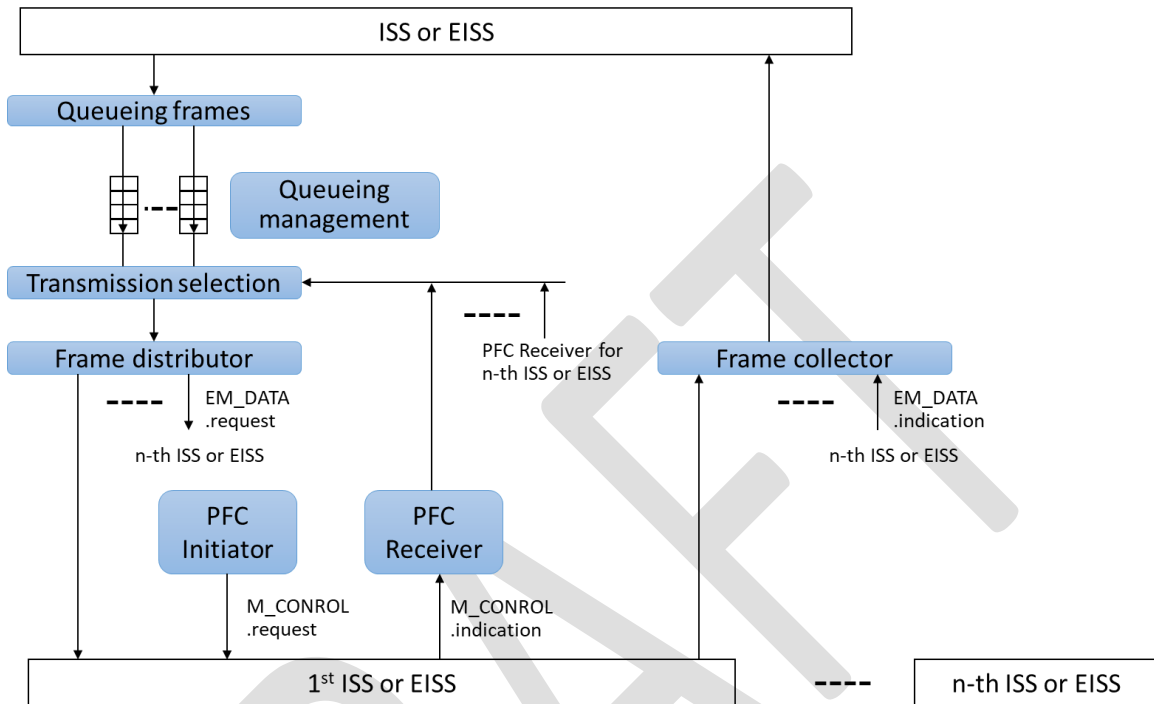
22

23

In order to ensure transfer of information between terminals in a dynamically changing wireless environment within the allowed latency as required by factory applications, a fast and efficient queueing control and forwarding mechanism to multiple links is needed while maintaining required QoS for the application. For this purpose, we consider the applicability of the PFC

1 (Priority-based Flow Control) protocol specified in the [IEEE Std. 802.1Q-2018](#), as shown in [Figure](#)  
 2 [17](#).

3



4  
 5  
 6

**Figure 17 PFC aware system queue functions with Link Aggregation  
 (Rewritten Figure 36-4 in Std. 802.1Q-2018)**

7 It should be noted that the application of PFC has been so far used in data center environment<sup>10</sup>.  
 8 However, when used in a factory environment such as the one described above, the performance  
 9 and efficiency of the PFC protocols can be degraded significantly due to reduced available  
 10 bandwidth between terminals. A real time video streaming is a good example illustrating when  
 11 the performance of the PFC function can be improved when operating in varying radio  
 12 propagation conditions. Traffic for the video stream is allocated high priority in normal operation  
 13 condition (i.e. traffic type for video has higher priority than traffic for critical applications  
 14 according to Table I-2 in the Std.802.1Q-2018 [7]-[15]). With varying RSSI, the available bandwidth  
 15 between terminals is reduced. In real time video streaming application, video quality can be  
 16 adapted to available link bandwidth (along the end to end path) at the codec source. However,  
 17 until this video adaptation is complete, while the bandwidth of the link is low and the video quality  
 18 is degraded below its usable level, streaming is paused, although further packets are incoming to  
 19 the queueing buffer which are not useable any more. This is the current operation of PFC because  
 20 data loss is not allowed in a data center for which the PFC protocols was originally designed.

21 Since the video packets are no longer usable, pause operation and preserving the video packets  
 22 is no longer valid during this transition period. During this period, the packets for steaming shall  
 23 be discarded and critical traffic shall continue to be sent. A more efficient operation method is to  
 24 discard the unusable video packets until useful video packets are sent again. This occurs when

<sup>10</sup> Section 36.1.1 in [IEEE Std. 802.1Q-2018](#) says “Operation of PFC is limited to a data center environment.”

1 video adaptation to a lower quality matching the available bandwidth, or the link bandwidth is  
 2 recovered naturally or by switching to a new link with sufficient bandwidth.

3 If another ISS (or EISS) connection becomes available for the video stream application, data frame  
 4 can then be forwarded dynamically at the bridge. (Table 17)

5 **Table 17 Gaps between Current PFC (IEEE Std.802.1Q-2018) and Functions to be enhanced**

| Current PFC (IEEE Std.802.1Q-2018)  | Functions to be enhanced  |
|---|---|
| <b>8(max) links can be independently paused and restarted by queue control. Only no loss is acceptable for data center environment.</b> | Not only “pause” but also “discard” are acceptable <del>depending on data attributes to express a variety of</del> QoS requirements <del>in of</del> factory applications <u>permit it</u> .  |
| <b>There is no specific description about “frame distributor”</b>   | Dynamic frame distributor mechanism is required to follow rapid changing bandwidth and to avoid burst losses for each ISS/EISS connected to a wireless media.   |
| —   | It is required to have negotiation function with <u>a</u> factory applications <del>based on data attributes. for D</del> data rate reductions <del>is requested if the factory application indicates reduction is “acceptable” in the data attributes to determine if this reduction is acceptable to the application.</del> |

6

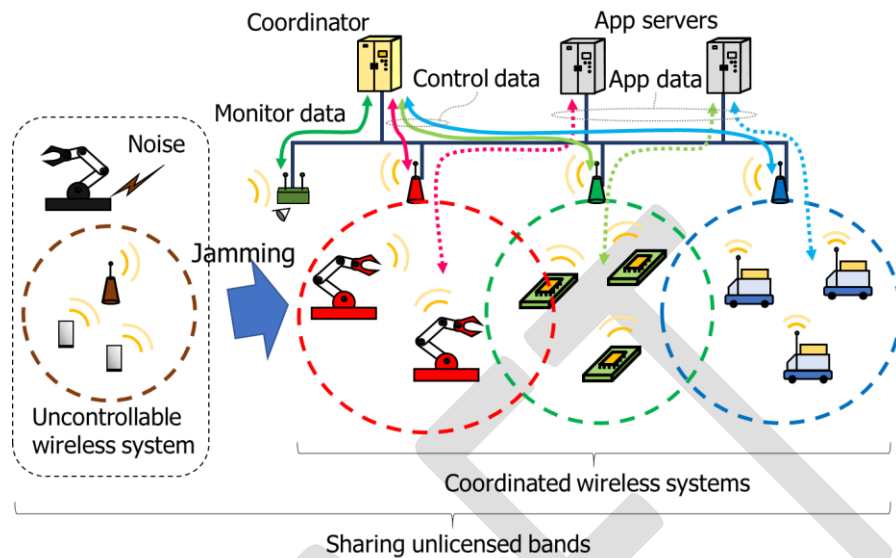
7 The issue here is to adapt to rapid changes in wireless environments while ensuring a variety of  
 8 QoS requirements across the end-to-end connection of the whole network. The rapid flow control  
 9 at the bridge based on information of data attributes and flow control over the entire network  
 10 shall work together by a coordinator as shown in [Figure 2](#).

11 **Coordination among wireless systems in unlicensed bands**

12 As for the factory IoT, wireless technologies which work in unlicensed bands are used in many  
 13 cases because they have large cost advantage in network deployment. Normally, such unlicensed  
 14 bands wireless technologies have MAC layer functionalities ~~which that~~ enable coexistence with  
 15 various wireless systems; CSMA/CA of Wi-Fi and frequency hopping of Bluetooth, for example.  
 16 These functionalities make network deployment simple. However, stable quality of service is  
 17 difficult to keep with such simple schemes especially when many wireless systems share the same  
 18 wireless resources. It is because each wireless system, which consists of multiple wireless stations  
 19 and is managed by a base station, works independently based on own probabilistic approach  
 20 without any coordination with the other wireless systems. In the factory IoT usage scenarios,  
 21 many wireless systems work in a broad area, which is not separated completely in terms of  
 22 wireless resource, and such competition of wireless systems in unlicensed bands are unavoidable.

23 To mitigate the impact of the competition in unlicensed bands, it is necessary to coordinate  
 24 wireless systems in factory as much as possible. To assign channels of each wireless system  
 25 according to required bandwidth of applications is a simple example of the coordination. Both  
 26 distributed and centralized manner can be applied for the coordination. However, wireless  
 27 systems need to be connected to the same wired network for exchanging control data. Wired

1 network of the factory IoT needs to handle the control data for the wireless system coordination  
 2 in addition to application data of each wireless systems. **Figure 18** illustrates an overview of  
 3 centralized type of coordinated wireless systems.



4  
 5

**Figure 18 Overview of coordinated wireless systems**

6 Ideally, all the wireless systems in an area should be connected to the same network and  
 7 coordinated together. However, it is difficult to root out uncontrollable wireless systems in all the  
 8 cases and noise from non-communication devices like machine tools also need to be taken into  
 9 consideration. It is necessary to monitor wireless channels, analyze behavior of such interferers  
 10 and estimate available wireless resources accurately for allocating wireless resources according  
 11 to demands of applications. Wired network of the factory IoT needs to handle the monitoring data  
 12 as well.

13 As latency of control data exchange and monitoring data exchange among wireless systems  
 14 becomes lower, more efficient wireless system coordination becomes available. Improvement of  
 15 latency of bridging is one of issues for the efficient coordination of the wireless systems.

## 16 **Future directions towards enhancements for Flexible Factory network**

### 17 **End to end network control and coordination**

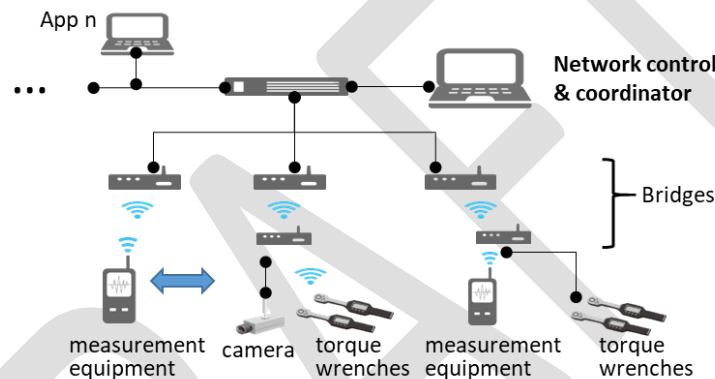
18 Within flexible factory scenarios, networks need to meet various traffic requirements and provide  
 19 QoS at application level. There are different types of data flow between factory applications and  
 20 network nodes, such as devices, access points, gateways, switches, bridges, and routers. To keep  
 21 QoS across the factory network with prioritized control, data attributes are introduced at network  
 22 nodes. Data attributes are defined based on the type characteristics of applications and its  
 23 corresponding requirements. These attributes are attached to the data field and mapped to  
 24 appropriate traffic types. Setting data attributes for factory applications rather than extending  
 25 traffic types is essential for backward compatibility to existing standards.

26 Centralized control and coordination mechanism is required in order to ensure end-to-end QoS  
 27 provisioning over the entire factory network, even in the brownfield where various facilities and

1 equipment with different standards, of different generations, and by different vendors coexist.  
2 The following control functions over the wired/wireless network are anticipated for coordination  
3 purpose.

- 4 1. Control of data flows across wireless links.
- 5 2. Joint coordination of frequency channel and forwarding paths.
- 6 3. Spatial control for wireless links, i.e. power and antenna directivity.
- 7 ~~3.~~

8 Coordination is achieved by a coordinator managing the factory network. As illustrated in [Figure](#)  
9 [19](#), the Bridge/AP of each sub-network is deployed for various applications. L2 data frames need  
10 to communicate between individual devices or towards the application server. The control policy  
11 could be provided by the coordinator for each sub-network for the ease of implementation, in  
12 cases where they should be provided on individual device basis by an application specific policy  
13 template.



14  
15 **Figure 19 typical network scenario for flexible factory IoT**

16 Wireless link or path quality is changing rapidly (from milliseconds to seconds) due to multipath  
17 fading and shadowing in the closed environment of factories where human, product and material  
18 handling equipment e.g. forklift trucks and AGVs (automated guided vehicles) are moving. It is  
19 required to reserve minimum bandwidth for priority application by enhancing bridge functions,  
20 despite the degradation in the local link quality. For the purpose of reliability, queueing and  
21 forwarding, mechanisms for redundancy need to be defined to use data attributes over the  
22 network. The coordinator can set policies for transmission of application data in a way that  
23 tolerates the degradation in the network due to the bandwidth changes. The control policies  
24 should be established to ensure the low priority bulk data transfer does not impact the  
25 transmission of the high priority critical messages and important data.

26 For coordination and control of a factory network made up of several tens of systems, a huge  
27 tightly-controlled network and computing resources would be required. Tight control directly  
28 conducted by the coordinator is impractical. This implies the necessity for hierarchical control  
29 consisting of (1) centralized coordinator which implements the global control for coordination of  
30 independent systems to satisfy requirements of each factory applications, and (2) the distributed  
31 coordination agent on each individual Bridge/AP which serves as local control for each system  
32 according to control policy. The control policy implies how radio resources of time, frequency,  
33 and space are utilized to optimize operation of entire network in a factory.

1 To realize the hierarchical control, more information needs to be concentrated on the centralized  
2 controller enabling an autonomous operate in quick response. For this purpose, the following  
3 three items need to be considered for standardization.

4 A) Control policy: messages and interfaces between a coordinator and various systems.

5 ~~B) Information on wireless environment: link/path quality.~~

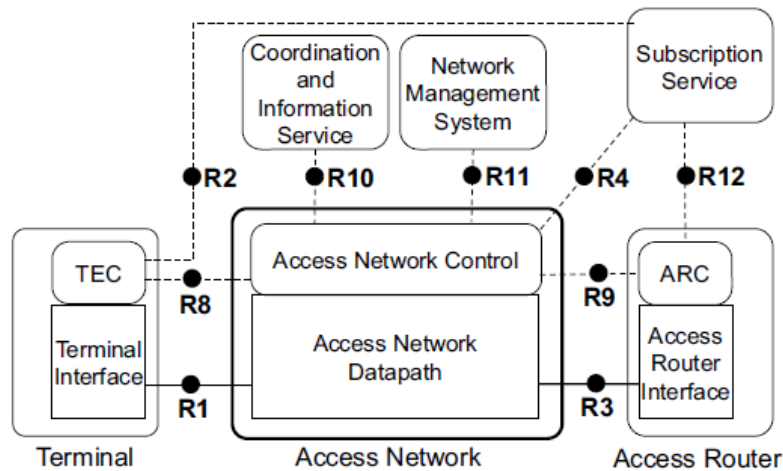
6 B)

7 C) Data attributes: common information including various requirements, e.g. data rates (or  
8 data size at an application level and data frequency), latency, affordability of packet loss.

9 The information is helpful for transportation of various traffics by better control of flows  
10 when mapping to traffic classes, scheduling and forwarding~~Traffic types expressed by~~  
11 three bits may not be sufficient for factory applications.

### 12 An unified network reference model

13 Network reference model (NRM) for flexible factory IoT network is a generic representation which  
14 includes multiple network interfaces, multiple network access technologies, and multiple  
15 applications. The NRM defined in IEEE P802.1CF [20][16] is appropriate for this purpose and can  
16 be used to generalize the concept of centralized configuration paradigm and to explain how data  
17 attributes are managed as informative description as well. The minimum enhancement could be  
18 achieved by creating a factory profile consisting of the reference model and data attributes. Detail  
19 investigation is required if any protocols shall be added.

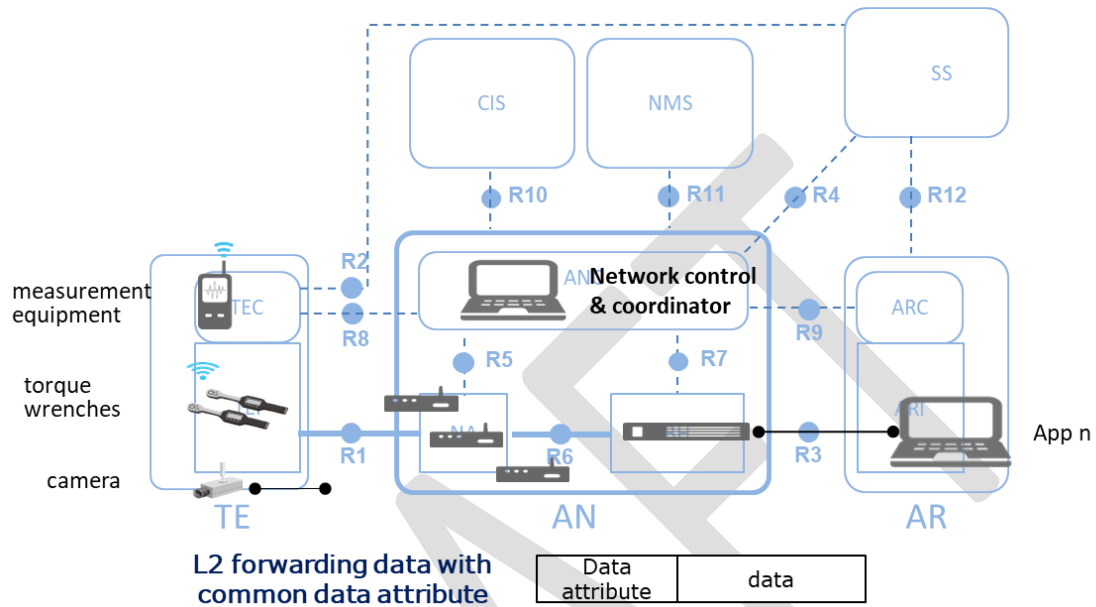


20  
21 **Figure 20 network reference model defined in IEEE P802.1CF**

22 The aforementioned network scenarios shown in [Figure 20](#) can be mapped to [IEEE Std 802.1CF](#)  
23 NRM as depicted in [Figure 21](#). Bridge/AP represents the node of attachment (NA) providing  
24 wired/wireless access through R1 to the terminals (devices). L2 data frames with common data  
25 attributes are aggregated and forwarded to the second level bridges, represented as backhaul

1 (BH) through R6 datapath interface. The coordinator is located in the access network control (ANC)  
2 providing control policy to the underlay bridges and APs through R5 and R6 control interfaces<sup>11</sup>.

3



4

5

**Figure 21 mapping factory network to 802.1CF NRM**

6

The centralized coordinator fits well in the role of ANC provides enhancements to IEEE 802.1 protocols and procedures, e.g. SRP, for time sensitive applications. More complex TSN use cases benefit from the complete knowledge of streams in the network, especially for the ones going through wireless mediums, which are stored and processed by the coordinator.

7

8

In the case that performance requirements cannot be guaranteed as promised due to e.g. bandwidth fluctuation, the coordinator may respond quickly based on its knowledge of the global network resources and adjust parameter settings amongst all bridges/APs. Control policy shall be provided to keep sufficient resources to accommodate short-term variance and to re-allocate network resources adaptively to establish stable streams even on wireless medium. It ensures that the end-to-end QoS provided by the factory network meet the different requirements from the wide variety of factory applications.

9

10

Further to the aforementioned considerations, when wireless is used in factory networks and systems, some TSN features may be required to perform ~~at the same level~~ seamlessly as they would over the wired portion of the network. This implies additional challenges that need further consideration, such as the impact on latency and reliability of the wireless links at Layer 1/2.

11

12

The radio environment in the factory also poses additional challenges. The NIST report on "Guide to Industrial Wireless Systems Deployments" [12][8] gives good guidance on planning and

13

14

<sup>11</sup> Refer to Clause 5 of the Draft-IEEE Standard P802.1CF/D2.1 [20][7] for detailed information of network reference model (NRM).



1 deploying wireless systems within the factory environment. Characterization of radio channels in  
2 factory environments may additionally help, if available, with such planning and deployment.

### 3 **Conclusions**

4 Communication in factories has until now been mainly wired communication. There are increasing  
5 expectations for the use of wireless connectivity amongst machines in the manufacturing and  
6 factory processes. Future industrial factory networks are expected to use more wireless to reduce  
7 the installation cost as well as to enhance flexibility. As such, the factory network needs to support  
8 the successful operation of various wireless applications.

9 This report addresses integrated wired and wireless Internet of Things (IoT) communications in  
10 the factory environment, and includes use cases and requirements with a focus on bridged Layer  
11 2 networks. It presents problems and challenges observed within the factory and reports on  
12 possible solutions for overcoming some of these issues in order to enable flexibility within  
13 factories.

14 One distinct aspect of factory networks is that the physical devices connecting to the network are  
15 used to control and monitor real-world actions and conditions. This requires the provisioning of  
16 QoS for a variety of traffic types that may be characterised as either periodic or sporadic. In a  
17 flexible factory, humans are engaged in the control and monitoring system and therefore need to  
18 be interconnected with the network in order to interact with physical devices and machinery.

19 When the factory network is extended over radio, some incompatibility in QoS provisioning  
20 between wired and wireless segments becomes apparent due to unpredictable variations in the  
21 available bandwidth over the radio segment. In order to overcome the variable environment for  
22 wireless communications, coordination amongst network elements is required.

23 The report considers communication requirements for six categories of wireless applications,  
24 which are classified according to their purpose.

25 For factory applications, QoS latency tolerance is classified into small, medium or large. Bandwidth  
26 tolerance is classified into wide, medium or narrow, and the tolerance for packet loss is classified  
27 into loss intolerant or loss-tolerant. This implies that factory applications may require a large  
28 number of QoS classes, more than the 8 classes specified in IEEE Std 802.1Q. To deal with a large  
29 number of QoS class requirements, defining usage of tag fields may be needed for precise and  
30 fine QoS control over L2. Any priority tag must be understood in both wired and wireless  
31 networks, which may require tag translation amongst the two.

32 Future industrial wireless communications will take advantage of TSN functions and features  
33 specified in IEEE 802.1. The wired/wireless integrated networks for future flexible factories IoT  
34 scenarios should be able to accommodate various applications with different end-to-end QoS  
35 requirements. These requirements can be met by closing the gaps within the following  
36 functions:

- 37 • End to end stream reservation in a wired/wireless integrated network
- 38 • Wireless link redundancy for reliability and jitter improvement
- 39 • Adaptation to rapid changes in wireless environments

1 • Coordination among the wireless transmissions in the unlicensed bands

2 Coordination mechanism is required in order to ensure end-to-end QoS provisioning over the  
3 entire factory network. The following control functions over the wired/wireless network are  
4 anticipated for coordination purpose.

5 4. Control of data flows across wireless links.

6 5. Joint coordination of frequency channel and forwarding paths.

7 6. Spatial control for wireless links, i.e. power and antenna directivity.

8  
9 For the purpose of reliability, queueing and forwarding, mechanisms for redundancy need make  
10 use of data attributes over the network. The coordinator can set policies for transmission of  
11 application data in a way that tolerates the degradation in the network due to the bandwidth  
12 changes that can occurs over the wireless links.

13 Hierarchical control system consists of centralized coordinator and distributed coordination agent  
14 on each individual Bridge/AP. For the purpose of satisfying requirements of each factory  
15 applications, the following considerations need to be standardized.

16 a) Control policy: messages and interfaces between a coordinator and various systems.

17 b) Information on wireless environment: link/path quality.

18 c) Data attributes: common information including various requirements, e.g. data rates  
19 (or data size at an application level and data frequency), latency, affordability of  
20 packet loss.

21 When wireless is used in factory networks and systems, some TSN features may be required to  
22 perform seamlessly as they would over the wired portion of the network. This implies additional  
23 challenges that need further consideration, such as the impact on latency and reliability of the  
24 wireless links at Layer 1/2.

25 The radio environment in the factory also poses additional challenges. Characterization of radio  
26 channels in factory environments may additionally help, if available, with such planning and  
27 deployment. {the conclusion section needs further review after the new draft.}

28 ~~A factory is called a “brownfield” where various facilities and equipment with different standards,~~  
29 ~~of different generations, and by different vendors, coexist in the same sites. There is also a variety~~  
30 ~~of data from factory applications flowing into network nodes and data attributes attached to the~~  
31 ~~data field that need to be introduced for priority control at each node. The hierarchical control~~  
32 ~~consisting of global control for the coordination of independent systems and distributed and local~~  
33 ~~control for each system according to control policy is promising to adapt to short term~~  
34 ~~fluctuations of wireless link and to optimize the wireless resources of an entire network in a~~  
35 ~~factory. Such operation is explained by network reference model to configure a flexible factory~~  
36 ~~profile.~~

37 ~~Two approaches to realizing coordination have been described depending on situations where~~  
38 ~~single standardized but decentralized and independent wireless systems coexist, and~~  
39 ~~heterogenous wireless and wired systems coexist in the same space. Each of them will be efficient~~  
40 ~~and both will be better to improve performance.~~

1

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