FLEXIBLE FACTORY PARTNER ALLIANCE

5G and Evolution of Wireless Technology to Drive Future Factories

- Digitalization of Manufacturing Facilities by AI and IoT in the New Normal Era -

Introduction

At factories, in order to move for automation, to save labor, and to support various-kinds and various -volumes production, opportunities are increasing to see scenes, such as control of robots and automatic carriers, real-time information from workers and manufacturing equipment, inspection and analysis using AI (Artificial Intelligence) and IoT (Internet of Things), and work support by ICT (Information and Communication Technology). Now that we are in the new normal era, factories are adopting a production process that enables remote monitoring and remote work without workers sticking to the site.

Under these circumstances, wireless communication has become indispensable in order to provide means of communication for automated carriers and workers with mobile devices, and to improve the ease of installation of equipment with communication interfaces. Furthermore, due to the evolution of wireless LAN (Local Area Network) and high expectations for 5G (Fifth-generation mobile communications system), it is expected that the use of wireless communication will be further expanded in the future.

On the other hand, sufficient information is not available, that includes how to use wireless communication and how to install it well in factories. With this regard, FFPA (Flexible Factory Partner Alliance) is receiving questions from factories and equipment vendors.

This position paper provides FFPA's views on three major questions as follows:

- What are wireless use cases in factories?
- What is 5G introduction scenario?
- How is the future factory vison changed by digitalization?

FFPA is hoping that this position paper will serve as a reference document to consider a vison of the future factories supported by wireless communication.

FFPA established cooperative relationship with 5G-ACIA (5G Alliance for Connected Industries and Automation) and signed Memorandum of Understanding in April 2020 and exchanged views on this position paper with them during the development. Both organizations continue to seek more collaboration in the future.

1. Expectations for wireless communication at manufacturing facilities

1.1 Macro trends surrounding the manufacturing industries

Manufacturing industries are required to address long-term macro issues (Fig. 1). In factory operations, automation and labor saving are accelerated due to labor shortages and a decrease in skilled workers, mainly in developed countries. Furthermore, for the production at factories, it is necessary to adapt to intensifying global competition and diversifying customer needs. Therefore, on-demand manufacturing is being promoted to produce the required products, with the required amount, and at the required timing.

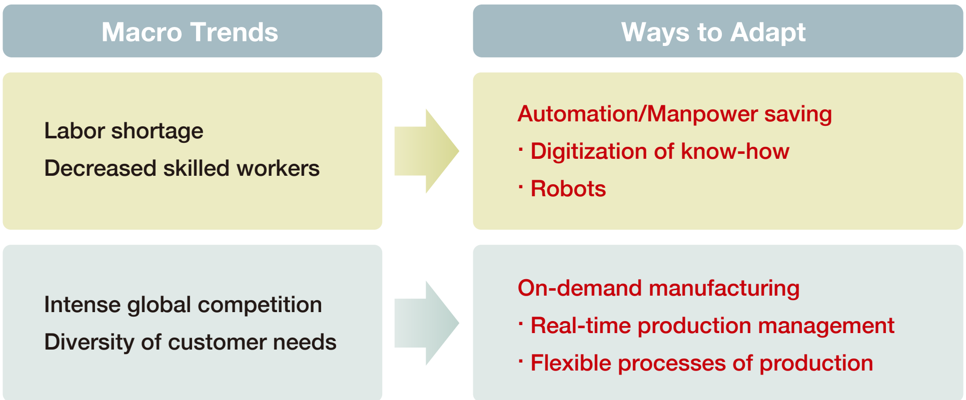


Figure 1: Macro issues in manufacturing industries.

In order to address these macro issues, it is necessary to change conventional operations and processes by utilizing ICT. Furthermore, due to the pandemic of the new coronavirus infection (COVID-19), automation/labor saving and remote monitoring/remote work utilizing AI and IoT are becoming more important.

In the future, it is expected that the manufacturing facility will evolve that can digitize know-how, can facilitate control of machines such as robots, and can easily collect digitized information to flexibly adapt to changes in operations and processes.

1.2 Flexible Factory

Flexible Factory represents an evolved site for flexible on-demand manufacturing of variable product types with variable production volumes, emphasizing mobility and configurability of manufacturing facilities [1]. In the network of the above factory, wireless communication is indispensable, and is responsible for communication with mobile devices and carriers. Wireless communication is also important for network connections from retrofitted sensors and frequently relocated production machines and equipment.

Production machines in the factory are usually used for 20 years, or even 30 years or more. According to a plan of the factory as a whole, new equipment and communication systems are introduced step-by-step for each process at the time of equipment renewal or equipment addition. Therefore, the wireless communication systems with various standards and generations are mixed in the same site. The applications and venders of communication systems are also different there. In the case of wireless systems, coordination among the systems is not expected so far and communication problems may occur. In addition, the operating wireless system may not be able to perform stable communication due to layout changes, movement of surrounding structures, and interference from other wireless systems in the factory.

The Flexible Factory requires stable wireless communication without disturbance. However, for the purpose of dealing with stable operation, it is difficult to have specialists who are familiar with wireless communication technology in the factory. Therefore, it is necessary to have a mechanism that visualizes the status of wireless communication and enables integrated management to be doable even by non-experts. FFPA is promoting standardization activities for the SRF wireless platform to facilitate visualization and integrated management of wireless communications. Multiple wireless systems built on this platform will mitigate interference with each other and will enable them to work together.

One of the most relevant concerns about using wireless communication is security. The International Electrotechnical Commission (IEC) has developed the standard for network and system security of industrial communication networks, namely IEC 62443 [2]. Based on the standard, security guidelines for secure factory network with wireless communications [3] have been released by FFPA and a white paper addressing security needs for 5G [4] has been published by 5G-ACIA. As this position paper does not contain security aspects for wireless communication, the above documents are recommended to read.

2. Wireless communication in factories

2.1 Use cases of wireless communication

At the workshop held by FFPA, the major use cases actively using wireless communication were mentioned. They include (1) control of AGVs (Automated Guided Vehicles) and AMRs (Autonomous Mobile Robots), and (2) work analysis and support based on videos from a large number of cameras located along the production line, and (3) product inspections to check defects such as foreign substances, burrs/chips, scratches/colors/dimensions, etc. performed using high-resolution images in the production line.

In the use cases drawn by 5G-ACIA [5], (4) light curtain system that detects the intrusion of people to ensure safety, (5) motion control that requires highly accurate alignment of components/devices, and (6) closed-loop control based on sensor information in chemical plants, etc. are added.

Table 1 summarizes the major wireless use cases [1] [6]. They are categorized as "Quality Supervision", "Factory Resource Management", "Display", "Equipment Control", "Human Safety", and "Others" for factory applications. From the perspective of wireless communication requirements, work support using videos that require large-capacity communication, motion control and emergency warning (intrusion detection) that require low delay, and various types of monitoring and management to collect a large amount of information are highlighted in the use cases.

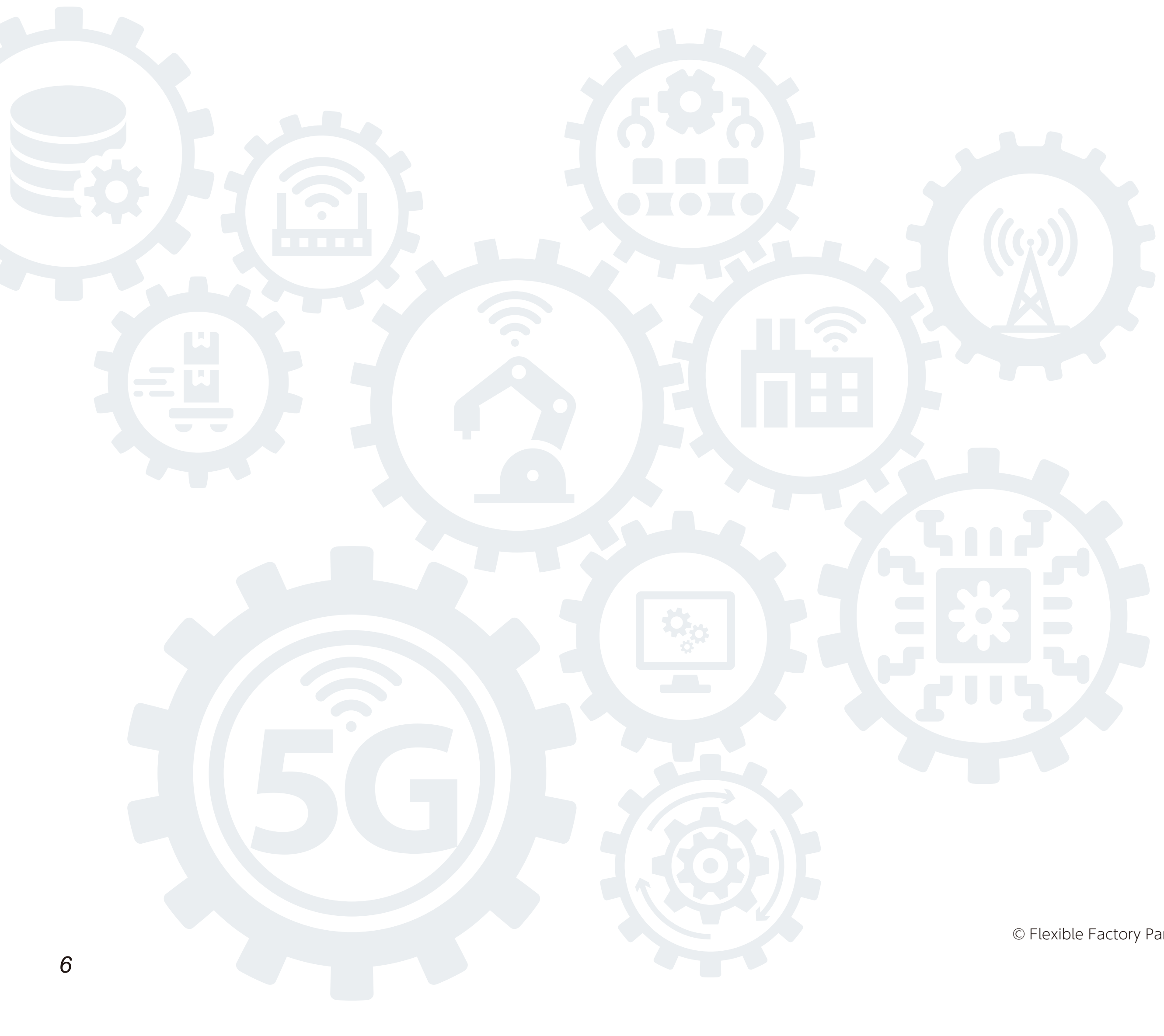
Table 1: Major wireless use cases (modified based on [1] and [6]).

Category	Description	Example for Use Cases
Quality Supervision	Collecting information related to products and states of machines during production.	Inline inspection, Machine operation/production recording, Logging, and Closed-loop control by sensor information.
Factory Resource Management	Collecting information about whether production is proceeding under proper environmental conditions, and whether personnel and things contributing to productivity enhancement are being managed appropriately.	Preventive maintenance for machine tools and equipment, Machine monitoring, Inventory control, Positioning, Motion analysis, and Facility-environment control.
Display	For workers, receiving necessary support information. For managers, monitoring the production process and production status.	Work instruction/support (wearable display, tablet, and screen), Retention-status display, and Andon board.
Equipment Control	Sending commands to mobile vehicles, production equipment, and receiving status information.	Motion control for robots and machines, Control for automatic carriers and rotary equipment, and Control for AGVs and AMRs.
Human Safety	Collecting information about dangers to workers.	Emergency warning (Intrusion detection) and safety reaction, Dangerous-behavior detection, Area monitoring, and Vital-sign monitoring.
Others	Communication infrastructure with non-specific purposes.	Program downloads.

2.2 Choice of wireless communication system

Wireless communications used in factories transmit various types of data: (1) small data with low delay for motion control, (2) a large amount of data for videos from cameras and massive data from sensors, (3) loss-tolerant data in environmental sensing, and (4) data limited to one-to-one communication for remote controls and displays.

For these reasons, factories will introduce the most suitable wireless communication system not choosing one type for all factory applications, considering requirements, power consumption and installation/operation costs, etc. As a result, various wireless systems are mixed in the factory. In the next section, wireless communication technologies are analyzed, that are intended for use in factories.



3. Technology Analysis

3.1 Wireless applications and wireless communication systems in factories

In the previous section, the use cases and their categories have been described. More specific applications in the use cases and the wireless communication systems are explained in the following.

Figure 2 shows the relationship between required response performance and communication range for typical applications. Some applications requiring communication within a single process line such as machine control, and inline inspection may have relatively narrow range, but small amounts of data tend to be exchanged frequently with quick response performance. Environmental sensing data such as temperature and humidity, require less frequent communication and a wide communication range to collect the data. In this way, the characteristics required for communication differ depending on the application.

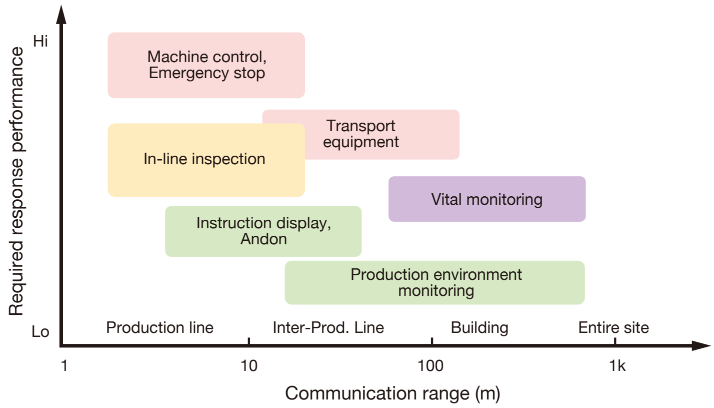


Figure 2: Relationship between required response performance and communication range for typical applications.

Figure 3 shows what kind of wireless technology is selected in the factory based on the relationship between communication distance and communication speed. At the manufacturing facilities, functional and performance requirements for wireless communication differ depending on the application, so a wireless communication system that suits each application is selected. For this reason, various wireless communication systems are mixed and operated at the manufacturing facilities.

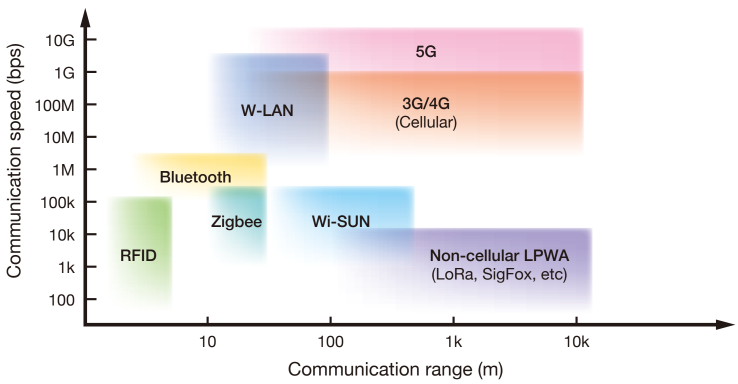


Figure 3: Examples of wireless technology selection for factory use cases.

Typical wireless technologies are explained in the following with providing how they are used in factory environments.

Wireless LAN (2.4GHz/5GHz)

Wireless LANs have a very high commutation speed and can be easily connected to wired LANs with a bridge. So they are widely used for wireless tools to AGV control, etc in manufacturing facilities. Relatively large data such as high-resolution images, vibration data, and torque waveforms are sent in a short time. They are also used to connect devices such as smartphones and tablets finally to reach the factory backbone network. The wireless LANs consume rather high power, and are mainly used for devices with constantly powered or with a large-capacity battery. A typical communication distance is several tens of meters.

Bluetooth/BLE (2.4GHz)

Bluetooth is often used to pair a handheld terminal or a barcode reader with a smartphone or tablet carried by a worker. In particular, BLE (Bluetooth Low Energy) is low power-consumption and therefore, it is used in many battery-powered IoT devices. BLE is also used for beacons and is used to locate positions of workers and things in factories. Bluetooth or BLE is mainly used for communication with a distances of several meters.

Zigbee (2.4GHz/Sub-GHz)、Wi-SUN (Sub-GHz)

While a communication speed is low, Zigbee or Wi-SUN has good coverage taking the advantage of a low frequency (Sub-GHz band) compared with Bluetooth or wireless LAN. Furthermore, it is possible to cover a wide area by making multi-hopping connection. For this reason, Zigbee or Wi-SUN is used for environmental monitoring such as temperature and humidity sensors in scattered positions, and telemetering of electricity meters. It features a low power consumption, and is used for applications operating on a battery (primary battery) for several years.

Non-cellular LPWA (Sub-GHz)

Communication such as LoRa and SigFox has a very low transmission rate, but it enables long-range transmission over 10 km with low power consumption. It is primarily used for telemetry applications and can also be used for outdoor tracking in combination with GPS.

LTE/4G (700MHz~3.6GHz)

While various wireless communication systems such as 920MHz band, wireless LAN, and Bluetooth are used from IoT devices to the gateways, mobile communication systems LTE/4G is used when uploading data from gateways to a server or clouds in difficult environments where wired LAN cannot be used or wide area communication is required.

In addition to the communication systems as listed above, the 5th-generation mobile communication system (5G), which is now being introduced in the market, will expand the choices of users. 5G has the potential to accelerate use of wireless communication in factories and will significantly change operation of machines and equipment as well as manufacturing facilities.

3.2 Use cases of 5G in manufacturing facilities

In Japan, 3.7GHz, 4.5GHz, and 28GHz frequency bands have been newly assigned to 5G. These bands are licensed to mobile network operators, allowing them to fully utilize clean, non-interfering bandwidth for many business and industrial applications. In addition, non-public 5G (Local 5G) is available, where some parts of the 4.5GHz and 28GHz frequency bands are allocated to local governments or landowners for their limited sites e.g. factories and farmland. 5G provides excellent communication performance such as high speed, low latency, and massive connections to meet various service requirements. Another benefit is the high security supported by device authentication of 5G core networks. These features are suitable for wireless networks in manufacturing facilities, both indoors and outdoors (Fig. 4).

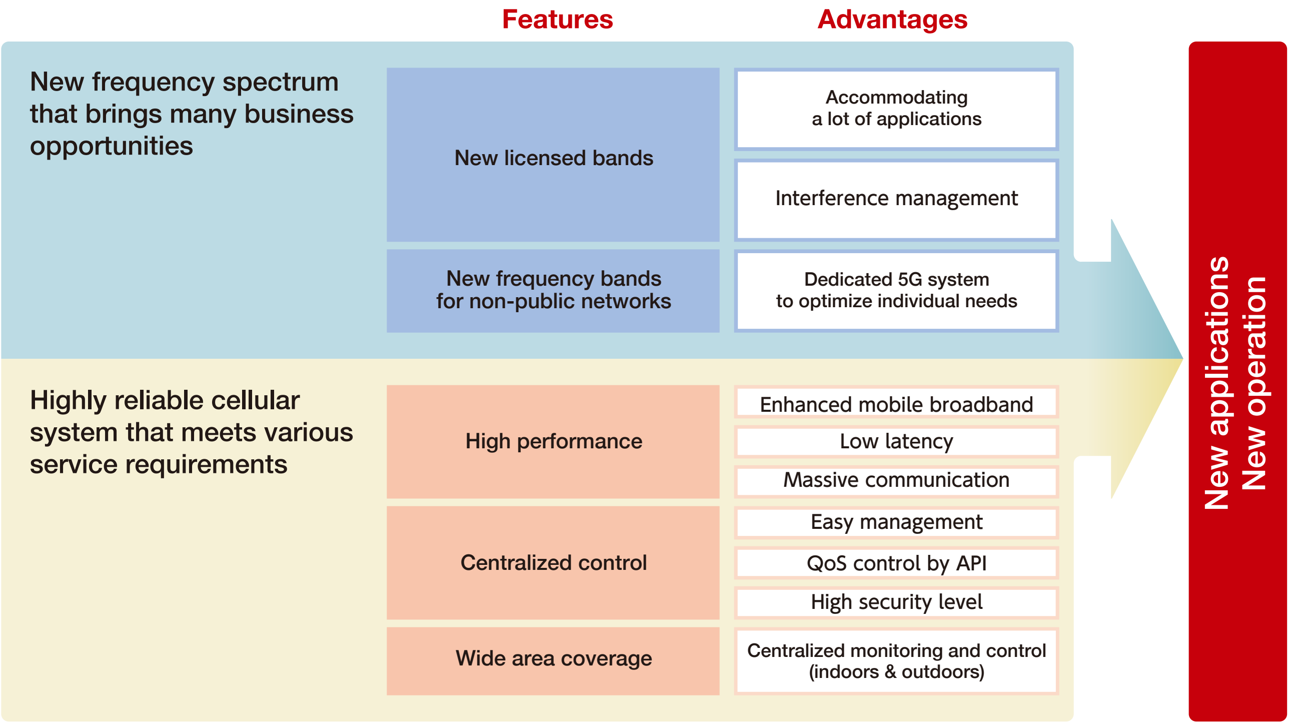


Figure 4: Advantages of 5G.

Many companies in Japan have conducted 5G field trials to take advantage of these benefits for factory reforms (Table 2).

Table 2: Major 5G field trials in manufacturing facilities.

Partners	Location	Overview of field trials
DOCOMO, OMRON and Nokia	Kusatsu factoy of OMRON	Radio wave propagation and transmission experiments, layout-free production lines using Autonomous Mobile Robots, human-machine collaboration using 5G. (FY 2019-)
DOCOMO, FANAC, and Hitachi	FANUC headquarters factory and Hitachi Omika Factory	Radio wave propagation and transmission experiments, verification of wireless control of production equipment, remote maintenance, complete wireless factory by 5G. (2019-2021)
ATR, KDDI, DENSO, and Kyushu Institute of Technology	Kyushu Institute of Technology and DENSO Kyushu	Verification of complete wireless control of pick-and-place industrial robots and layout changes. (Jan.-Feb. 2019)
KDDI, DMG MORI	DMG MORI Iga Campus and Tokyo GHQ	AI-enabled chip removal solutions of image recognition and automatic cleaning nozzle using 5G. (FY 2019-2020)
SoftBank, Sumitomo Electric	Factory of Sumitomo Electric	Images and sensing data are collected in real time via 5G and analyzed by AI to automatically detect changes and anomalies in equipment and human behavior. (Mar. 2020-)
NTT Communications, Bridgestone	Bridgestone Technical Center and Product Plant	Radio wave propagation test, communication performance test, various application tests using local 5G. (June 2020-)
NTT Communications, DMG MORI	DMG MORI Iga Campus	Radio propagation and communication quality tests. Remote operation of an AGV via local 5G. (May 21, 2020 to April 2021)
Fujitsu, Fujitsu Telecom Networks	Oyama plant in Tochigi Prefecture	Data transmission of high-definition images collected by multi-point cameras. AI-powered security system that quickly detects suspicious behavior through motion analysis. (March 27, 2020-)
Fujitsu, Fujitsu Network Solutions, Cable media waiwai	Cable Media Waiwai (5G core) and test customer (edge equipment)	Real-time transmission of high-definition video with various sensors for monitoring, sensing, and remote work support. (Oct. 2020-)
Sumitomo, Sumitomo Shoji Machinex, NICT, etc.	Plant in Kitaazumi-gun Nagano Prefecture, Takebashi and Otemachi Office in Tokyo	Verify properties of the millimeter-wave band, remote video monitoring, VR conferencing, and transmission of large amounts of data from 4K 360-degree cameras. (June to August 2019)
Sumitomo, Sumitomo Corporation Global Metals, Sumitomo Shoji Machinex, Grape One	Summit Steel Osaka Factory	automated visual inspection based on AI analysis and remote quality verification based on high-definition video transmission. (Jan. 2021-)

For example, ATR, KDDI, DENSO, and Kyushu Institute of Technology have jointly demonstrated the control system for pick-and-place industrial robots using wireless connection by 5G, that increases layout flexibility in an actual factory [7][8]. The system configuration is shown in Fig. 5. A base station of 28GHz frequency band was built in the factory, and the signal cables connecting the industrial robot, 3D scanner, and control PC were replaced with 5G wireless networks. The entire picking area including the robot was measured by a 3D scanner and the collected 3D data were transmitted to the control PC via 5G. The control PC estimated the positional relationship between the part and the robot, and commanded the robot to pick the part and to place it on the conveyor belt accurately. The movement of the robot was optimized by the motion planning technology by Kyushu Institute of Technology. The pick-and-place was successful without human teaching even when the robot placement was changed (Fig. 6).

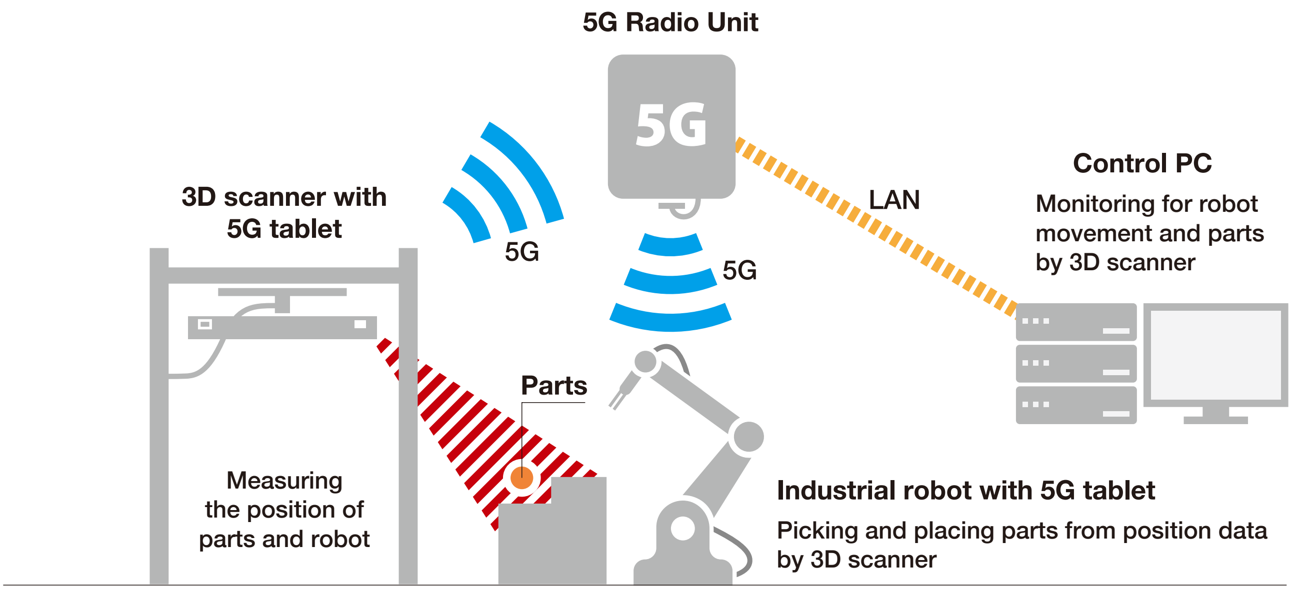


Figure 5: System diagram of the field trial.

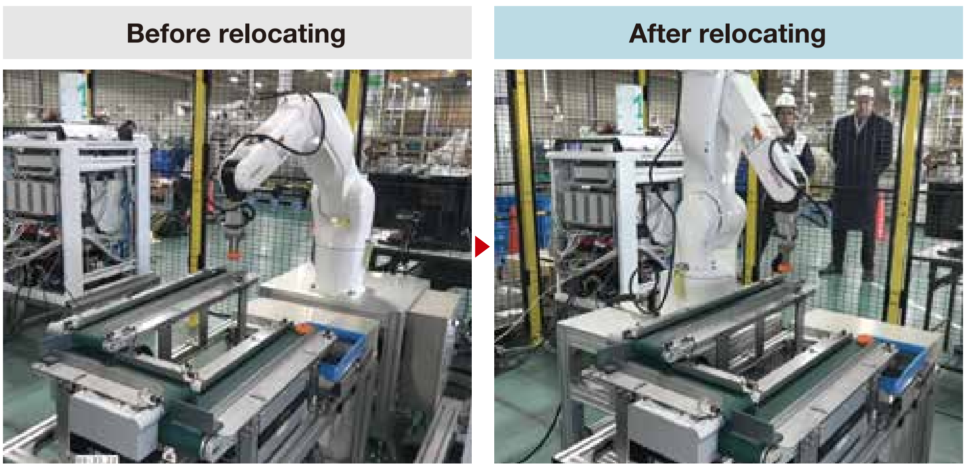


Figure 6: Industrial robot relocation in the field trial.

From June to August 2019, Sumitomo Corporation carried out the Japan's first local 5G field trials to verify the properties of the millimeter-wave band and to demonstrate remote video monitoring, VR conferencing, and transmission of large amounts of data from 4K 360-degree cameras. Sumitomo and its partners also conducted the pilot experiment of non-public 5G (Local 5G) at the Osaka Factory of Summit Steel from Jan. 2021 as a consignment project supported by the Ministry of Internal Affairs and Communications [9]. In this experiment, an automated visual inspection based on AI analysis and remote quality verification based on high-definition video transmission have been tested. The experiment results were analyzed with the aim of spreading the use of non-public 5G for similar purposes.

Figure 7: Summit Steel Osaka Factory (provided by Sumitomo Corporation).

3.3 A scenario of 5G introduction

Utilization of wireless communications has been increased in factory facilities for various kinds of purposes. Different communication qualities are required depending on the purpose for each use case or application. Figure 8 shows an example of required communication qualities. Some use cases require 5G performance of low latency, while there are remaining use cases with no need of 5G. On the other hand, since many wireless systems are already attached to or embedded in production machines and equipment, which usually operate for over decades, it is expected to be very difficult completely to replace all existing wireless systems by 5G from the viewpoint of return on investment. From these reasons, 5G in a licensed band and wireless technologies in unlicensed bands will become a mutually complementary relationship. The best wireless technology for each use case will be chosen from 5G, wireless LAN, Bluetooth and other wireless technologies in unlicensed bands depending on the requirements for each use case or application, e.g. required data transmission speed, delay tolerance of data transmission, number of accommodated wireless devices, range of wireless communication, indoor use or outdoor use, radio wave environment in which wireless devices are utilized, power consumption of wireless devices, and initial and running costs of wireless systems.

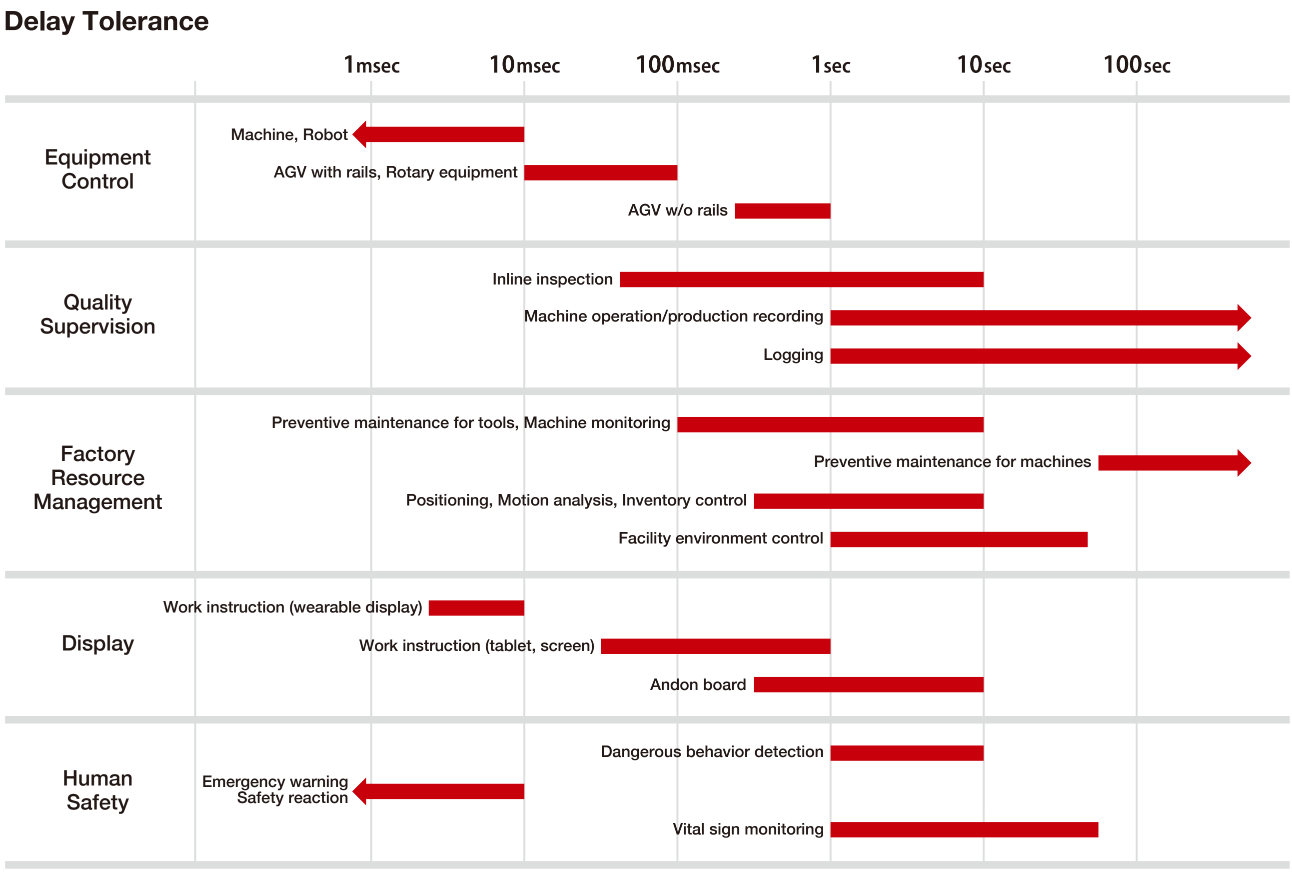


Figure 8: An example of required communication quality (Delay tolerance) [1].

While utilization of wireless communication is expanding in factory facilities, the adoption of 5G is increasing especially for the use cases which need the 5G performances and also which are newly created on the basis of 5G. On the other hand, there are many use cases which can be achieved by using ordinary wireless technologies in unlicensed bands such as wireless LAN and Bluetooth. Therefore, FFPA has drawn up a scenario in which these technologies are also increasing together with 5G.

In future factory facilities, there will exist wireless use cases which need the 5G performances of high speed, low latency, and massive connections in wireless networks, e.g. wireless robot control, 4K/8K image wireless transmission for image inspection, and AR glasses for work support (Figure 9).

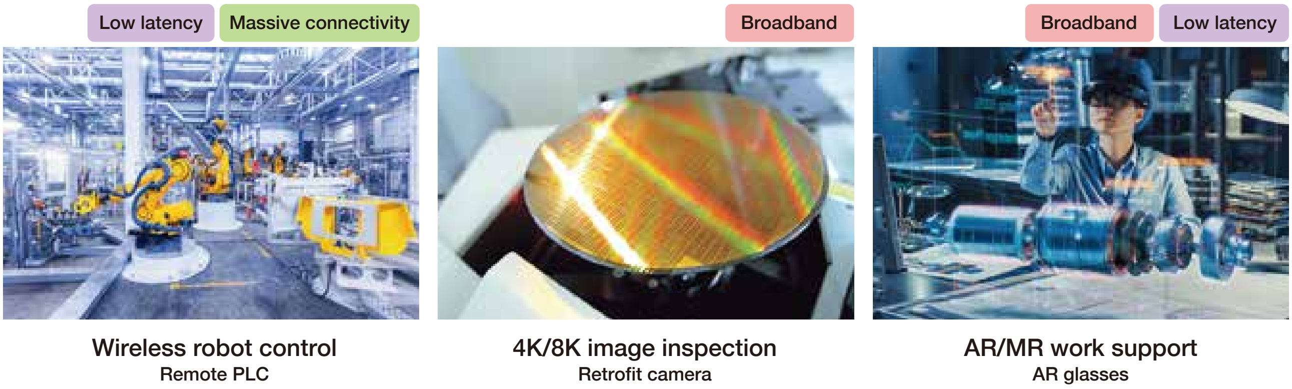


Figure 9: Use cases utilizing 5G in factory facilities.

The advance on miniaturization and price reduction of 5G wireless devices will lead to the combo devices which have multiple radio access technologies (multi-RAT) of both 5G and wireless technologies in unlicensed bands such as wireless LAN and Bluetooth. Appearance of the multi-RAT combo devices (e.g. tablet PC, wireless camera, AR glasses) is expected to encourage wireless utilization further in factories (Figure 10). FFPA has been standardizing the wireless platform which can realize more reliable wireless communications and more efficient utilization of limited frequency resources based on the coordination between 5G and wireless technologies in unlicensed bands.

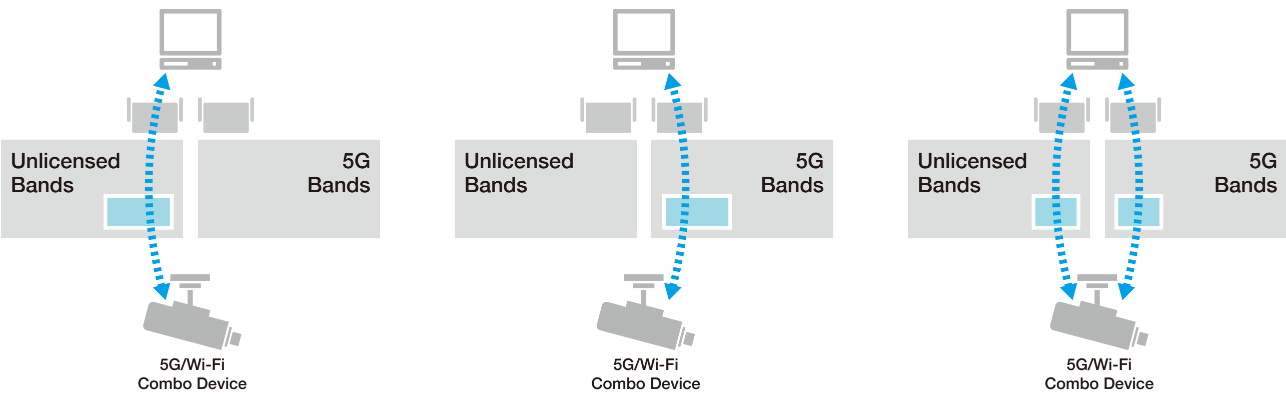


Figure 10: An example of coordination between 5G and wireless technologies in unlicensed bands.

4. Factory of the future with wireless communications

4.1 Digitalization of manufacturing facilities

According to the white paper published by Ministry of Economy, Trade, and Industry of Japan, the problem of skill succession is getting worse in the manufacturing industry. 86% of manufacturing companies are or willing to digitize the skills at manufacturing and production sites. The visualization and sharing of skills are the top reason (71%) for digitalization of skills [10]. This shows the need to build the scheme for everyone to become an expert or to automate the work of an expert by digitizing the skills of an expert.

OMRON is developing the real-time coaching system using AI and IoT technology (Figure.11). A lot of human works are required in the production of many models in small quantities. The detailed operations of human works differ depending on the proficiency of the worker. The real-time coaching system analyzes the operations of the workers, detects whether they are performing appropriate operations, and gives correction instructions, if necessary. By utilizing this system, it is possible to support the operations that are prone to mistakes and enable workers to efficiently improve their proficiency.

Figure11: The image of analyzing the operations of the workers (OMRON).

At the Amberg factory of Siemens (Germany), monthly production is on the scale of millions for 1000 types of automation system-related electronic components and products. The data collected from 50 million manufacturing processes are analyzed by the industrial cloud (MindSphere), and the results are reflected to improve manufacturing process. The rate of automation in the factory has reached 75%, and the defective product rate, which was about 500-600 dpm (defect per million) in the case of manufacturing by workers, has been reduced to 12 dpm. This is an example improving not only production efficiency but also product quality assurance by increasing the rate of automation.

4.2 Full automation / Human-robot collaboration

The manufacturing facilities are various and vary greatly depending on the products and the type of production. Therefore, FFPA believes that the approach to the above issues is not only full automation but also human-robot collaboration. In fact, the introduction of collaborative robots that operate in the same space as humans is rapidly expanding [11].

In addition, SmartFactory^{KL}, the test bed installed at German Research Centre for Artificial Intelligence (DFKI), is verifying that a production line can be constructed by combining production modules made by multiple vendors. They aim to realize a flexible production line by transporting products between among production modules by transfer robots such as AGV or AMR instead of a fixed conveyor belt.

4.3 Digital twin

Adapting to intensifying global competition and diversifying customer needs, the flexible and efficient production, distribution/sales, maintenance/after-sales service are required based on the entire engineering chain consisting of research and development, product planning, product design, and process design and supply chain consisting of ordering and production management.

Therefore, it is expected that the digital twin will develop. The digital twin collects the operating status of equipment and facilities and environmental information of the physical space in real time and modeling the equipment and equipment in the cyber space for visualization and simulation (Figure 12).

The digital twin digitizes not only information on equipment and facilities at the manufacturing facility, but also the movements and behaviors of workers. It enables visualization of proficiency and appropriate work support in virtual space. It is expected that efficient and effective skill succession will be possible.

Figure12: The image of digital twin (Siemens factory at Amberg).

Whether the direction of evolution of the manufacturing facility is full automation or human-robot collaboration, information on equipment and workers in the physical space is analyzed and evaluated in the virtual space for feedback to the physical space. Therefore, the digital twin will be indispensable in the factories of the future.

Since the digital twin sends and receives wide variety of large amounts of data and information between physical space and virtual space, communication technology is required to meet various requirements at the same time. In addition, it is expected to utilize wireless communication in order to improve the flexibility that is essential in the Flexible Factory.

4.4. Roadmap of FFPA

FFPA develops SRF wireless platform standards as a basis for stabilizing diverse wireless communications mixed in the manufacturing facility. Figure 13 shows the roadmap of FFPA. SRF wireless platform in version 2.0 and later provides a flexible wireless industrial network in which the coordination control between 5G and unlicensed bands wireless technologies is conducted. In version 2.0, the status of 5G network is monitored and the policies/sessions are controlled. In version 3.0, 5G network will be directly controlled using API (Application Programming Interface) by updating configuration based on application information. Moreover, SRF wireless platform in version 2.0 and later also conducts the coordination control of wired- and wireless-integrated industrial networks.

As the use of the SRF wireless platform expands, use cases that utilize stable wireless communication will become widespread. In addition, FFPA is accelerating the introduction of the digital twin, which is necessary to realize full automation of manufacturing facilities and human-robot collaboration, and envisions the future in which digitalization of manufacturing facilities will be realized.

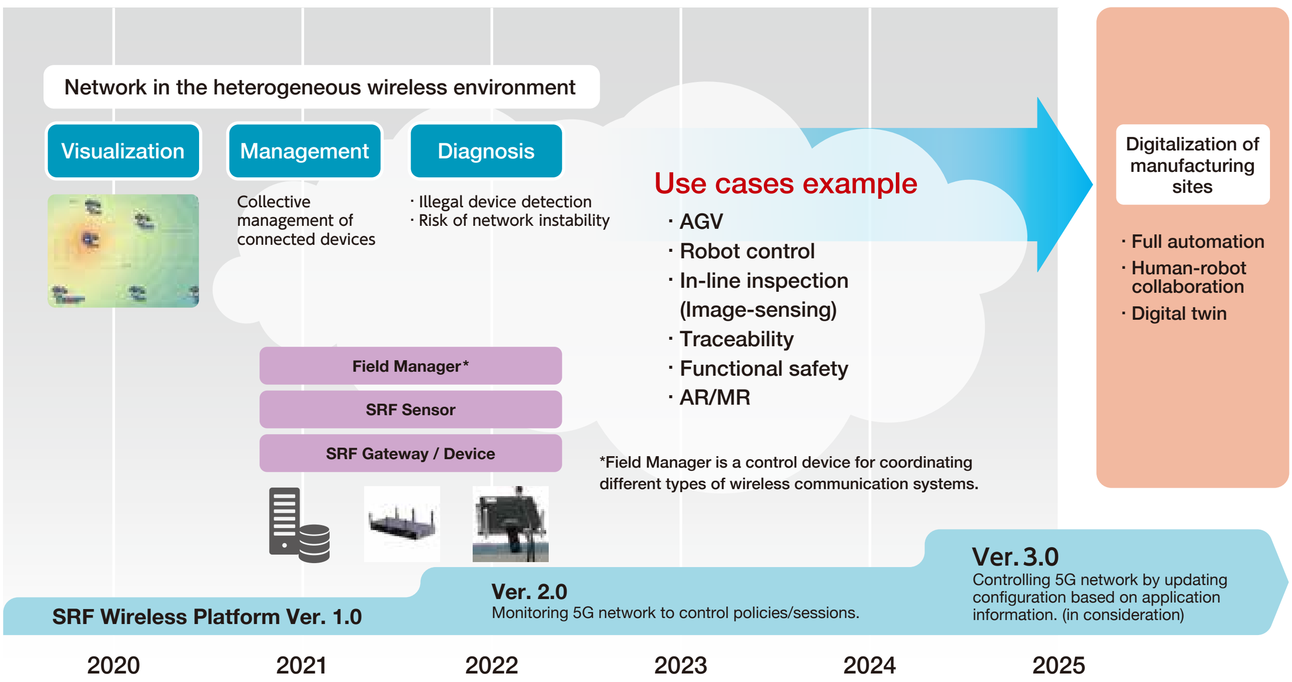


Figure 13: The roadmap of FFPA.

5. Conclusions

The environment surrounding the manufacturing industry has changed significantly due to various issues such as a shortage of workers, a decrease in skilled workers, work style reforms, intensifying global competition, and diversification of customer needs, as well as responding to the COVID-19 pandemic. There is an urgent need to shift to a production process that utilizes AI and IoT. It is necessary to realize the Flexible Factory emphasizing mobility and configurability of manufacturing facilities, where wireless communication is indispensable.

FFPA thinks as follows:

1. Promising use cases for using wireless communication include control of automatic carriers, image-based inspections, work analysis and support, and emergency stops and area monitoring to ensure safety. There is the best communication system that meets the requirements for each application, resulting in various wireless communication systems are mixed in the factory.

2. 5G, which is expected as a new wireless communication system, requires a license to use, on the other hand, there is no risk of interference with other wireless systems. With non-public 5G, users can occupy frequencies and can maintain high performance and reliability. 5G has features such as high speed and capacity, low latency, and a large number of multiple connections, and is excellent in terms of management and security. 5G will be the driving force for creating new applications and operations in factories while coexisting with Wi-Fi and Bluetooth taking advantage of their merits.

3. The future factory envisioned by FFPA is that the digitization of skills and works will progress toward two directions: factories with fully automated and with tightly cooperation between workers and robots. The manufacturing facility governed under the digital twin will connect cyber and physical factories to enhance the production process. In the future factory, wireless communication will be indispensable for information gathering, machine control and support for workers.

FFPA will contribute to realization of the future factory vison through promoting the SRF wireless platform that enables visualization and integrated management of various wireless communications including 5G.

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