Wireless Networks for Realizing Smart Factories

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"Smart factory" is a recent buzzword that refers to the increased utilization of IoT technology at production sites. This trend increases the importance of network environments especially wireless network, to connect everything. A diverse range of things must be connected to a production site network, from production facilities, various sensors, and cameras, to people working on site. However, their locations are not necessarily fixed. The use of wireless networks to efficiently connect these things to the network is increasing. However, production sites need to change line arrangements in accordance with the products being manufactured, which disturbs the onsite radio environment, necessitating a redesign of the network configuration. The wide variety of connected devices, including sensors and production facilities use different wireless technologies, including Wi-Fi, Bluetooth, and Bluetooth Low Energy (BLE). This situation is likely to cause signal interferences. Fujitsu offers technology to solve these challenges for customers and help them with the installation of wireless networks at their factories. This paper describes Fujitsu's wireless solution that ensures reliable wireless connections even at production sites with complex configurations. It also introduces its technology for visualizing a radio environment as a vital element for the installation, operation, and maintenance of the network, and its technology for designing the optimal wireless device configuration.

1. Introduction

The use of IoT technology at production sites has been gathering attention for some time under the buzzword "smart factory." A number of countries are now beginning new business initiative in the manufacturing industry such as Industrial 4.0[1] in Germany, Industrial Internet Consortium[2] in the United States, and Made in China 2025 in China. In Japan, the government announced the Connected Industries[3] initiative and put into effect a Connected Industries tax system (IoT tax system) in 2018. This tax system was established to support the introduction of systems, sensors, robots, etc., to facilitate the coordination and use of data among companies in the manufacturing industry with the aim of improving productivity.[4]

In the manufacturing industry, the value of using IoT technology lies in connecting things within production sites that had not been sufficiently connected in the past and connecting production sites to offices. It also lies in connecting companies to each other, connecting companies to end users, and improving productivity at production sites as well as in creating new business models. The targets of connection can be quite diverse, ranging from things like production facilities, sensors, and cameras to people like workers at production sites and maintenance personnel responsible for production facilities. In addition, data possessed by things and people, management information possessed by companies, and data describing real-time demand conditions in logistics and markets are connected. The sharing of such data among companies increases the chance of obtaining new knowledge and solving diverse problems.

At present, many companies are collecting data to understand the state of production facilities and workers at production sites. At production sites, the location of some facilities is not fixed due to, for example, the rearrangement of production lines. Furthermore, workers and automatic guided vehicles (AGVs) that transport goods are constantly in motion. In such an environment, wired connections would not always been efficient. For example, a rearrangement of production lines would require a new cable layout. The need for wireless networks in factories is therefore growing. There is also a need for "stable connection" to facilitate the collection of reliable data.

Aiming to make all sorts of manufacturing processes more efficient, Fujitsu proposes an IoT system centered about wireless technologies.[5)]

In this paper, we first summarize the requirements of a network environment at a production site and focus on the issues involved in using short-range wireless technologies such as Wi-Fi and Bluetooth. Next, we describe a high-reliability wireless solution (HRWS) for providing a stable communications environment. Finally, we outline a technology for visualizing the radio environment as a basis for installing, operating, and maintaining that solution and a technology for designing an optimal wireless device arrangement.

2. Issues surrounding smart factories

Network environments within a factory can be broadly divided into three types as summarized below.

1) Information system network

This network mainly targets office work using PCs such as groupware operations, mail processing, and various office tasks.

2) Inter-controller network

This network connects systems for controlling and monitoring production facilities such as supervisory control and data acquisition (SCADA), distributed control systems (DCSs), and human machine interface (HMIs). It also connects systems for managing factory machines and worker operations such as manufacturing execution systems (MESs).

3) Field network

This network connects control equipment such as a programmable logic controller (PLC), computer numerical control (CNC), and robot control equipment with devices in actual operation at a production site.

Up to now, these three networks have been constructed separately within a factory and have not been mutually connected. In smart factories, however, the trend is toward interconnecting them with the aim of improving productivity by analyzing the operating status of production facilities and achieving fully automatic production processes.

At the same time, setting up a wired network at a production site is not easy since the arrangement of production facilities often changes in accordance with the product being produced. For a wired network, cable layout must be redone every time the arrangement changes, but in contrast to an office environment, rewiring cannot necessarily be achieved under the floor. In such a case, cables have to be strung along the ceiling and dropped near the target equipment, which can be difficult.

Because of these conditions unique to production sites, the need for wireless networks is increasing. The following issues, however, must be resolved.

1) Stable connection

Production sites include metal and other materials that can block radio waves while having a configuration in which reflected waves and multipath signals can easily occur. As such, production sites do not provide a good environment for wireless networks. Even if wireless access points (APs) are optimally arranged, subsequent rearrangement, introduction of new production facilities, and the effects of moving objects such as AGVs can alter the radio environment and hinder wireless communications. In addition, APs are often installed at elevated locations within the factory building, causing inconvenience when revising AP arrangement every time the radio environment changes. There is consequently a need for a mechanism that can autonomously establish optimal paths without changing the installation locations of APs and other devices despite a change in the physical environment due to movement of facilities, etc.

2) Understanding radio wave conditions

In terms of wireless networks, a variety of communication standards exist. Low-power wireless technologies using Bluetooth or the 920 MHz band can be used to collect relatively small amounts of data as in the case of sensors. On the other hand, wideband wireless networks such as Wi-Fi are applicable to the collection of operation log data generated by production facilities. A Wi-Fi system can also be used for managing AGVs.

In short, different types of wireless systems are used at a production site depending on the target of production and the types and characteristics of the data to be collected. As a result, the current situation at each site is that a variety of radio signals are mixed in various combinations. Moreover, since the types of sensors used for collecting data will likely increase in the years to come, an increasing mix of radio signals is bound to occur. To prevent the generation of communication-disabling events caused by radio wave interference, it will be necessary to visualize radio conditions at the production site and search out an optimal arrangement of wireless devices.

3. High-reliability wireless solution

Fujitsu has developed an HRWS to facilitate wireless connections within a production site and resolve the issues described in the previous section. Based on Wi-Fi technology, this HRWS is a network that controls communications by using an original protocol. This section introduces Fujitsu's HRWS.

The HRWS has the following features required of a wireless network at a production site.

- Stable communications totally optimized by centralized control
- Expanded coverage area by multihop technology for relaying radio signals
- Ease of operation by maintaining multiple communication paths

These features will enable Fujitsu's HRWS to cooperate with a production system and improve productivity at a site.

A typical configuration of this HRWS at a site is shown in **Figure 1**. The network is configured by using the FUJITSU Network 1FINITY W series. This includes three types of wireless devices: a gateway router providing a wireless gateway, multihop routers serving as repeaters, and edge adapters serving as terminal communication adapters. In addition, a control server equipped with FUJITSU Network Virtuora WL software for controlling a wireless network is placed on the upstream of the gateway router in the network. The edge adapters, meanwhile, connect to terminals such as factory production facilities, measurement devices, and network cameras by wired LAN. Finally, a factory production data server connects to these on-site devices via the wireless network of the HRWS.

Virtuora WL communicates with wireless devices in its control range and continuously monitors radio conditions throughout the network. It also adjusts the radio parameters of individual wireless devices (transmission timing, channel, transmission power, and communication path). This continuous execution

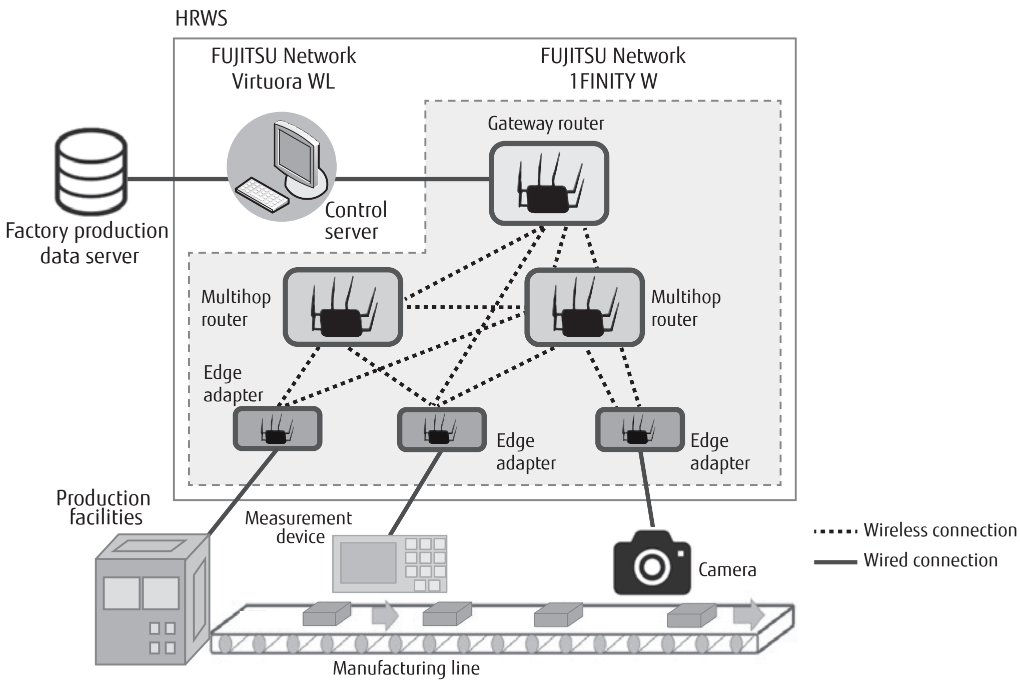

Figure 1
Typical configuration of HRWS.

of centralized control links the entire wireless network and achieves stable communications in the HRWS.

The following describes key mechanisms for achieving high-reliability wireless communications in this HRWS.

3.1 Interference-avoidance function

Wireless communication requires that the send and receive sides operate in step with each other. The wireless network of this HRWS has a timing synchronization function that synchronizes wireless devices to the timing of the controlling gateway router. The solution also performs channel hopping that switches the wireless communication channel every 100 ms. This function switches to another channel to continue wireless communications when interference is detected on the current channel.

This interference-avoidance scheme is shown in **Figure 2**. On detecting the presence of interference from wireless conditions collected from the wireless devices in the system, Virtuora WL instructs each wireless device to change its channel-hopping pattern and the entire network can operate in unison and interference can be avoided.

On detecting interference, existing Wi-Fi devices require approximately 30 s to switch channels and restart communications—no communications can be performed during this time. In contrast, switching in this HRWS can continue communications after a very short cutoff less than 10 μs.

3.2 Resistance to obstacles and movement

In a factory, the movement of cranes or AGVs, the rearrangement of machine tools, etc., can result in the blocking of wireless communication paths, thereby degrading communications. However, only one AP can be used by an existing Wi-Fi terminal even in such a radio environment. A terminal must therefore search for and connect to another AP when its current communication path is blocked, all of which generates a shutdown in communication.

Fujitsu's HRWS, in contrast, has a function for simultaneously maintaining two or more communication paths from a single edge adapter to multiple routers (multihop routers or gateway routers). Virtuora WL monitors the receive power at each of the communication paths aggregated at an edge adapter and uses that information to decide on an optimal communication path. Consequently, as an example, if a particular communication path is blocked by the presence of an

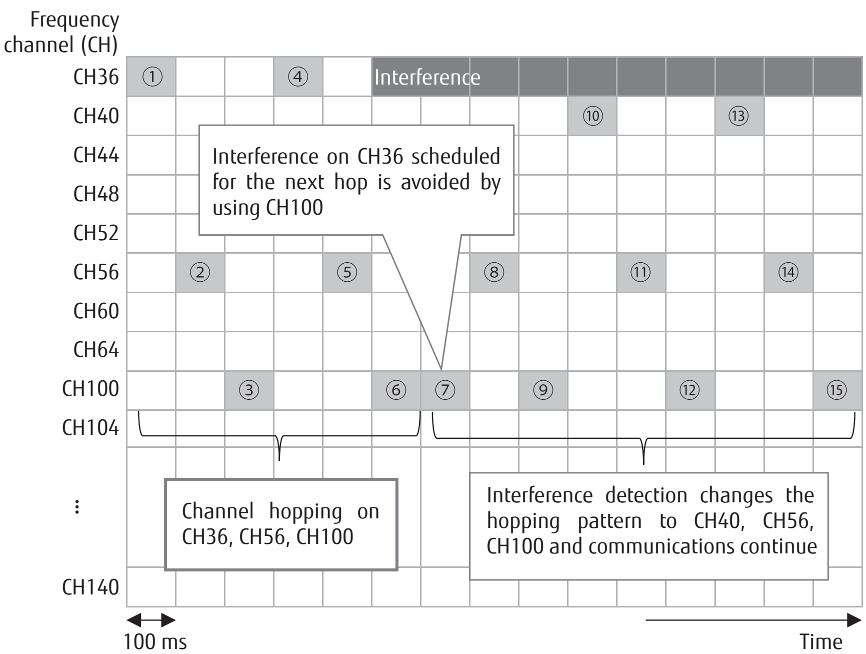

Figure 2
Interference-avoidance scheme.

obstacle and another pass is available, communications can continue on another one.

This multiple-communication-path-maintenance function is applicable even if edge adaptors are capable of movement. Specifically, a communication path handoff can be performed between routers in accordance with the receive level of each communication path to continue communications while an edge adapter is moving.

A comparison evaluation with Wi-Fi by using actual measurements showed that a wireless communication path blocked by some obstacle would shut down communications between a Wi-Fi AP and terminal for approximately 30 s. This is due to the time taken to reconnect to an alternative path after communication is interrupted. However, the HRWS could switch to another communication path immediately after the current path became blocked, resulting in no packet loss and no interruption of communications.

3.3 Extendibility of communication area

Fujitsu's HRWS has a function for extending the communication coverage area through the use of multihop communications. For example, a multihop router could be placed between a regular work area and a temporary work area where communications are needed. In this way, communication relaying of up to four hops can be performed to easily extend the communication area to a separated location. In this case, Virtuora WL would also perform centralized control of all wireless devices to achieve stable communications.

4. Wireless design technology toward field area networks

Fujitsu has developed radio wave simulation technology for designing and constructing—with a minimal number of processes—a variety of wireless networks (field area network) used at a production site. These include Wi-Fi, Bluetooth Low Energy (BLE), and the 920 MHz band wireless systems, as well as the HRWS described above. It has also developed radio wave visualization technology for solving such problems as "What radio waves are generated by these wireless networks?" "Why is there no connection?" and "Why has the connection been cut?" by visualizing radio waves that cannot be seen.[6]

4.1 Radio wave simulation technology

This technology can accurately calculate the state of arriving radio waves by 3D radio wave simulation. It simplifies the input of complex on-site environments through laser scanning and a simple layout editor and enables wireless devices to be appropriately arranged without having expertise in radio wave propagation.

Typical flow of radio wave simulation is shown in **Figure 3** and summarized below.

- Perform 3D digitizing of the space installing the wireless network by a 3D digitizer using a laser scanner (3D point cloud data)
- Model the 3D point cloud data as a space consisting of surfaces to reduce the scale of computing in radio wave simulation
- Execute radio wave simulation
- Analyze the results of simulation and determine optimal installation locations for the wireless devices

At an actual site, radio wave intensity can fluctuate greatly by about 100 times due to the movement of people and things. We have also developed technology for simulating the effects of such fluctuations. This technology can obtain time-series data on crowd density of the workers by image recognition and perform statistical processing on that data. It can also perform weighting processing on the results of the simulation in accordance with crowd density. Taking a space of about 1,000 m^2, this radio wave network design technology can complete calculations for an optimal arrangement of wireless devices in about 10 minutes. On the other hand, conventional technology took three days for the similar calculations.

4.2 Radio wave visualization technology

This technology automatically identifies radio waves by communications standard and visualizes interference conditions by channel and location. It can automatically identify Wi-Fi, Bluetooth, BLE, and ZigBee in the 2.4 GHz band and Wi-Fi in the 5 GHz band; all commonly used in factories and offices. Furthermore, in the 920 MHz band, which is expected to increase in use in the future, it can support standards such as LoRa, Sigfox, and other types of low power wide area (LPWA) communications, wireless smart utility networks (Wi-SUNs) used in smart meters, and radio frequency identifiers (RFIDs) used for product management in factories.

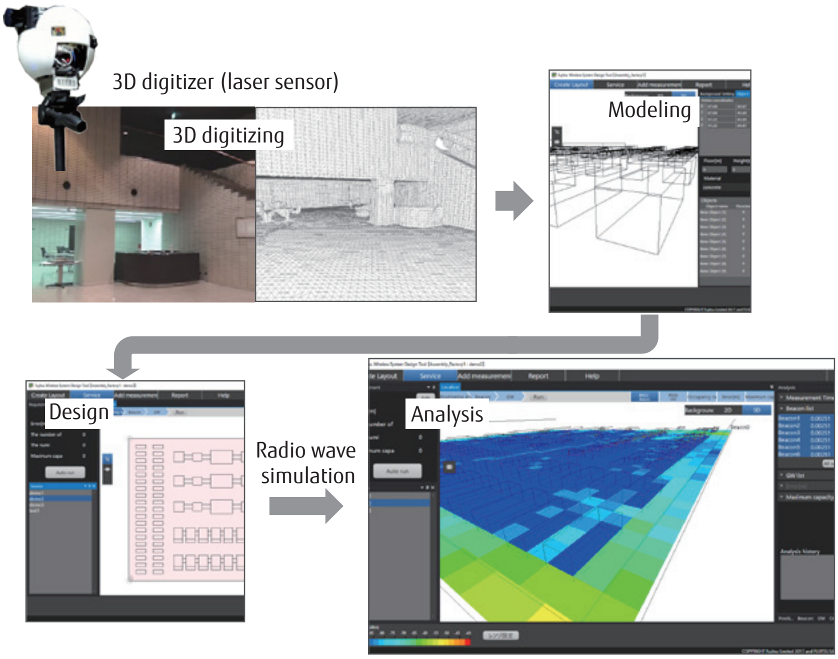

Figure 3
Flow of radio wave simulation.

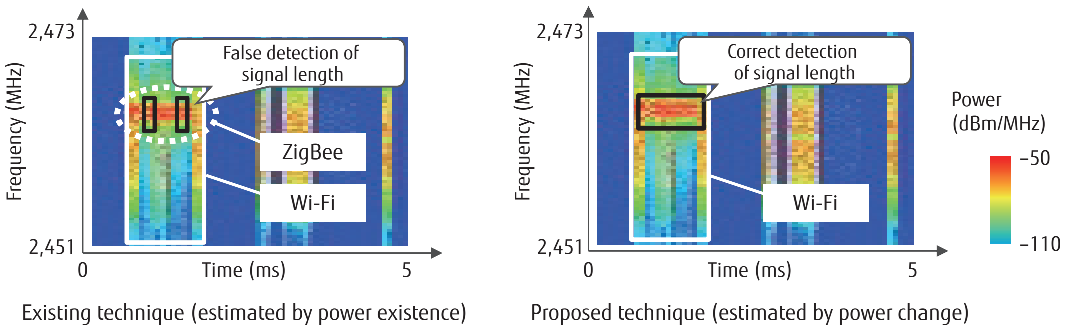

Figure 4
Example of separating overlapped signals.

Understanding the state of radio wave usage by radio wave visualization technology makes it possible to check for the presence of noise that can hinder communications, derive available radio channels, and select the most suitable radio channel. This technology consists of the following two-step process.

1) Spectrum shape recognition technology (preprocessing)

A common technique used for recognizing signal regions from spectrum shapes is to first detect the region for which the received power is above a certain threshold and then analyze bandwidth, center frequency, etc.[7] However, under a congested radio environment, signals can interfere with each other, making signal separation an issue.

In response to this problem, we developed technology that separates signals by focusing on the amount of change in power in the spectrum's temporal direction. We experimentally confirmed that this technology improves accuracy in estimating band occupancy rate.[8] An example of separating a ZigBee signal that is interfering with Wi-Fi is shown in **Figure 4**. While the existing technique can identify only part of the ZigBee signal, the proposed technique can identify it correctly.

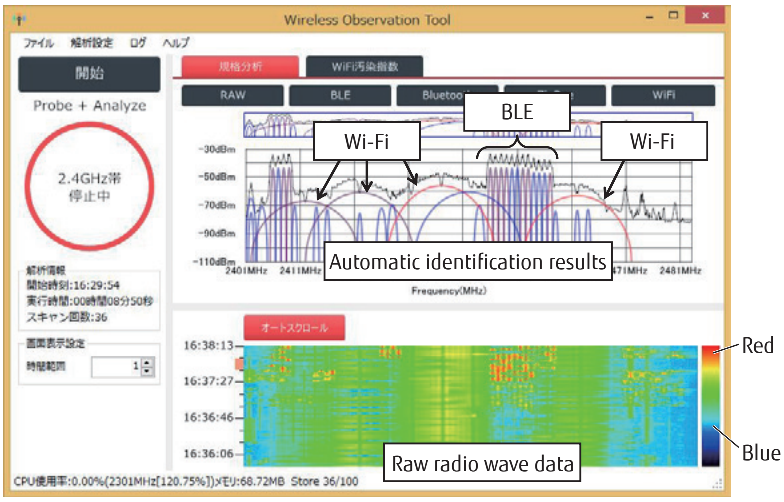

Figure 5
Survey results by radio wave visualization technology.

2) High-accuracy standard identification technology of wireless systems (post-processing)

This technology is based on a technique that calculates the cross-correlation value between an existing reference signal and the arriving signal for each standard of wireless system. We have also developed technology that uses frequency deviation to enable standard identification even in environments with much noise and interference[9] and technology that calculates with high accuracy parameters of Bluetooth and BLE signals whose short preamble signals prevent a sufficient correlation length from being obtained.[10] We experimentally confirmed that receive sensitivity in standard identification could be improved with these technologies.

These technologies, in particular, have made it possible to detect signals that could not previously be detected because of the effects of other signals at a level of sensitivity approximately twice that of the conventional method. An example of radio wave visualization applying these technologies is shown in **Figure 5**. In this example, radio wave visualization targets the 2.4 GHz band. The upper part of this tool shows the signal intensity of current radio wave conditions along the frequency band. It can be seen that Wi-Fi and BLE signals can be separated and detected. The lower part of this tool shows the temporal change in these conditions. The vertical and horizontal axes represent elapsed time and frequency, respectively, and the red and blue areas indicate strong and weak signals, respectively. This tool makes it possible to visualize with good accuracy the usage status of various types of radio signals that will come to be increasingly used at production sites and the radio waves generated by equipment and devices.

Fujitsu's radio wave visualization technology can also visualize congestion conditions even in environments where radio waves are likely to interfere with each other such as exhibitions and trade shows. It has been used to maintain radio quality at Fujitsu forums held at the Tokyo International Forum.

5. Conclusion

This paper described a high-reliability wireless solution for achieving stable wireless communications, a technology for visualizing a radio environment, and one for obtaining optimal location of wireless devices by radio wave simulation technology.

Going forward, Fujitsu will study network implementations that fit even better with specific on-site environments and will continue to promote the advanced use of networks at the production sites of many companies by leveraging the design technologies and solutions described in this paper.

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