Highly Reliable Operation Technology for Wireless Networks to Achieve Cyber-Physical Systems

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With digital innovation, companies, individuals, businesses, systems, and so on, are expected to connect organically through data. The key to realizing these connections is to create cyber-physical systems (CPS) that create stable connections between physical space (real space), where people and things exist, and cyberspace (virtual space), where processing is performed. In particular, connecting mobile entities such as people, things, robots, and cars to cyberspace requires the utilization of wireless technology. Wireless technology is evolving and diversifying on a daily basis, improving its convenience. At the same time, expertise in wireless technology is needed to obtain sufficient performance in accordance with the target application. Fujitsu Laboratories has been developing technology that enables wireless network managers without advanced expertise to easily design, construct, and operate wireless networks. This paper describes automatic design technology, interference control technology, and our approach to autonomous operation, which provide anyone with the ability to easily execute each phase of the design, construction, and operation of wireless networks.

1. Introduction

With the coming of the digital era, it is hoped that companies, individuals, businesses, systems, and other entities in society will become organically connected via data, that innovation will flourish, and that a prosperous society will be achieved. Society 5.0, which was proposed by the Japanese government in its 5th Science and Technology Basic Plan, describes a cyber-physical system (CPS). In CPS, AI in cyberspace (virtual space) analyzes a massive amount of information received from physical space (real space) where people and things exist and feeds back the results of that analysis to physical space. It is also envisioned that CPS will bring forth new value heretofore unseen in industry and society.[1] From here on, connecting physical space and cyber space in appropriate ways will become critically important. In particular, technologies that can be used to easily construct and operate wireless networks for connecting physical space and cyber space will play an important role in achieving CPS.

When setting out to construct and operate a new wireless network, a variety of tasks must be performed such as the selection of wireless standards, placement of base stations, and setting of channels so that all application requirements are satisfied. These tasks require expert knowledge and experience, so the process has so far depended on expert know-how and trial-and-error, all of which has been a factor hindering the achievement of CPS.

In response to this issue, Fujitsu Laboratories has developed technologies that enable even wireless network managers without advanced expertise to easily construct and operate wireless networks and that enable autonomous operation as well.

This paper describes automatic design technology for network construction and interference control technology for network operation. It also describes our efforts toward radio signal analysis technology for autonomous operation and standardization concerning that technology.

2. Current state of wireless networks and surrounding issues

This section describes the current state of wireless networks and issues that must be addressed to achieve CPS.

2.1 Current state of wireless networks

Physical space in which people and things exist comes in diverse forms. For this reason, networks that send and receive data that are collected from and fed back to physical space must be designed in accordance with each application.

In a factory, for example, individual networks for controlling and monitoring production facilities, managing factory work, and managing office work exist in parallel.[2] In addition, the ongoing progress in automated systems will likely lead to the incorporation of monitoring cameras, industrial robots, automated guided vehicles (AGVs), etc. into CPS. Here, real-time, reliable communications will be needed for industrial robots and broadband, uninterrupted communications will be needed for monitoring cameras.

Next, in a medical care facility, when an alarm sounds indicating a sudden change in a patient's condition, the delay or non-delivery of that data, which is actually small in size, is unacceptable. Furthermore, assuming that personnel in a hospital ward are using on-premises Voice over Internet Protocol (VoIP) communications to ask a doctor for instructions, voice quality must be maintained so that nothing is misheard or misunderstood. At the same time, an electronic health record system that doctors and nurses can easily access through hand-held devices must be able to send and receive large-sized diagnostic images smoothly with good response.

In education, reforms in school and class management that center on data are progressing (smart schools).[3] In this field, for example, a large-capacity wireless network would be required for simultaneously delivering digital materials consisting of a large amount of data to 50 students.

Wireless networks are also applicable to communications for people on the move and things that move about as well as for places like factories and stores where floor layout often changes.

2.2 Issues surrounding wireless networks

In general, a higher frequency band means that more data can be transmitted at one time (higher data rate) but only over a shorter transmission distance. For example, millimeter waves, which are expected to enable 10 Gbps ultra-high-speed communications in the fifth-generation mobile communications system (5G), use the 28 GHz high frequency band, meaning a transmission distance on a scale of several tens of meters. Moreover, in an actual environment, transmission distance can be greatly affected by shielding, reflection, etc. On the other hand, there is also SigFox technology that is representative of low-power wide-area (LPWA)[4] systems. SigFox uses the 920 MHz band in terms of frequency that is approximately 1/30 that of 5G. It is used to transmit small amounts of data that can be transmitted at a low data rate of 100 bps while achieving large transmission distances in units of kilometers enabling broad coverage. Yet, if multiple wireless networks are constructed at the same place, signal interference between those networks can present a problem. In such a situation, a survey of signal conditions must be carried out to optimize channel and power settings and the arrangement of radio equipment.

A number of services and technologies for surveying radio signals in use or for assisting in the construction and operation of a wireless network have begun to be provided.[5, 6] However, despite the availability of such services, analysis of the fundamental cause of a problem and selection of an effective countermeasure is extremely time consuming, and there are few experts who know how to use these services.

In response to these issues, Fujitsu Laboratories has developed technology that enables even wireless network managers without advanced expert knowledge to easily construct and operate wireless networks. The following sections introduce automatic design technology for network construction and interference control technology for network operation as well as our efforts toward radio signal analysis technology for autonomous operation and standardization concerning that technology.

3. Automatic design technology for wireless networks

This section introduces technology for automatically designing a wireless network that conforms to application requirements. It describes, in particular, design technology for achieving mobile streaming without interruptions using wireless LAN. This technology is implemented as an automatic design tool that even non-experts can use.

To begin with, the user uses a simple drawing function to input the building layout and candidate positions for installing access points (APs). Next, the tool selects the AP installation positions that satisfy requirements and automatically outputs recommended settings for channels and transmission power (**Figure 1**). These recommended settings are made so that a terminal can be continuously connected to multiple APs with no interruptions in a streamed program. In the past, design of AP positions required a computer with high computing power, but we have developed two technologies that can run on a commercially available laptop[note)].

The first one is signal simulation technology that makes use of an imaging method utilizing ray tracing technologies to treat radio waves as light. This system features high computational accuracy even for a complex environment with extensive reflection and diffraction such as a building interior, but it also suffers from long computational time. In particular, for environments having many structures or requiring repeated calculations, even a workstation with high computing power may require several hours to complete the simulation. To alleviate this problem, we developed original technology that omits the calculation of unnecessary signal paths, thereby, achieving computational speed more than five times faster than that of a commercial simulator.

The second one is high-speed AP placement technology. This technology examines performance by signal simulation while sequentially increasing or decreasing the number of provisionally placed APs to determine AP placement, transmission power, and channel settings that satisfy specified requirements with a minimum number of APs. At this time, the number of candidate combinations can be massive and a brute-force search could take several days. For this reason, under the condition of satisfying certain criteria by a non-linear evaluation function, we adopted a genetic algorithm for high-speed searching of a discrete optimal solution. Here, an “individual,” a key parameter of genetic algorithms, is taken to be a combination of various types of information corresponding to genes, namely, AP position, channel, and transmission power. In addition, assuming that multiple APs will be provided to maintain a connection if a terminal cannot connect to a certain AP for some reason, the evaluation function is defined, for example, to be the number of APs that a terminal can connect to at various positions

note) CPU: Intel Core i5-6300U 2.4 GHz, RAM: 12 GB.

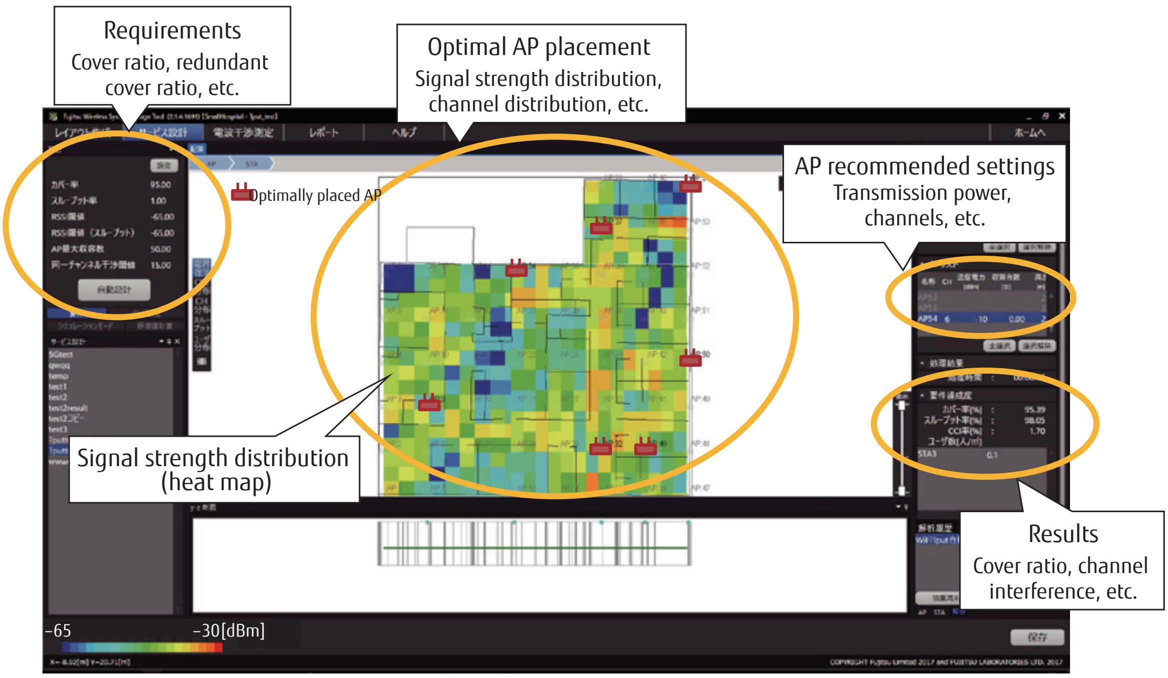

Figure 1
Screenshot of automatic design tool.

in a room (redundancy).

These two technologies can provide good results with a commercial laptop even in buildings having many small rooms, such as a hotel or hospital, where AP placement can be difficult. For example, the time taken to narrow down the number of candidate APs from 31 to 13 was under five minutes with these technologies.

The above presented an application example involving mobile streaming, but this automatic design technology could be applied to other applications by creating models so that evaluation functions satisfy requirements.

4. Interference control technology

This section introduces technologies for automatically diagnosing and preventing signal interference, an issue of concern when operating wireless networks.

4.1 Interference diagnosis technology

Fujitsu Laboratories previously proposed an algorithm for diagnosing interference by measuring response time on a terminal's physical layer with respect to AP transmissions.[7] This, however, requires implementation at the chip level, so the algorithm has not yet reached a practical stage. We have since developed a technique that can diagnose interference by combining two kinds of information that can be acquired by existing APs, namely received radio signal strength (received power) and data rate, from each terminal.

In wireless LAN communications, data rate drops when a communication error occurs. For this reason, data rate tends to be low when received power is weak and high when received power is strong. On the other hand, when interference occurs, data rate is low even if received power is strong. The technique that we developed makes use of these properties. It obtains the relationship between received power and data rate beforehand and determines the existence of any interference effect from the received-power and data-rate values obtained immediately before a disconnection (**Figure 2**). In an experiment using 40 tablet terminals in an anechoic chamber, the rate of detecting the interference intentionally applied from signal generating equipment correctly was 75% and 90% for the 2.4 and 5 GHz band, respectively, which are good results on a practical level.

4.2 Interference prevention technology

Fujitsu Laboratories previously developed technology for preventing signal interference within a single network by automatically allocating appropriate channels to each AP in wireless LAN.[7), 8)] This system allocated channels on the basis of the strength of interference signals between APs. Other companies' products allocated channels in the same way on the basis of signal strength, but when previously allocated systems from other companies were present nearby, there were cases in which interference would nevertheless occur as shown in **Figure 3**. To solve this problem, we developed technology for preventing interference even under complex conditions in which multiple wireless networks exist and the number of available channels is limited.

This technology first uses the existing system to allocate channels so as to minimize traffic volume (hereafter, amount of interference) that contributes to

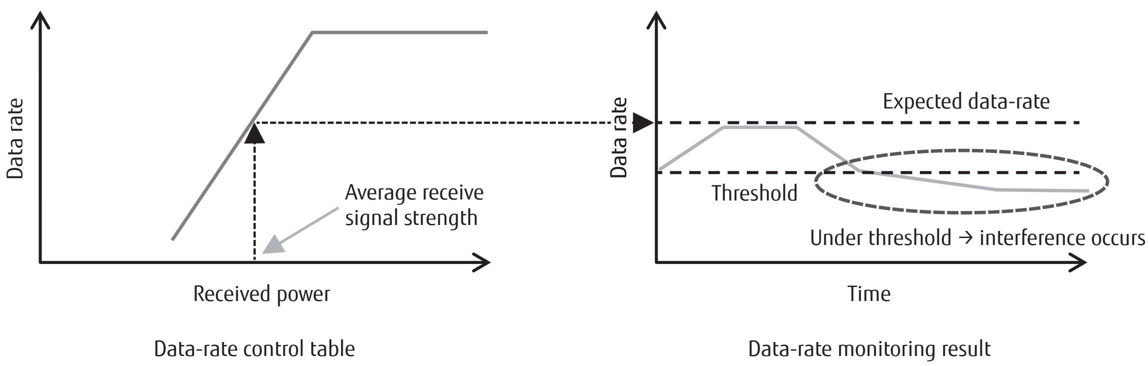

Figure 2
Interference diagnosis technology.

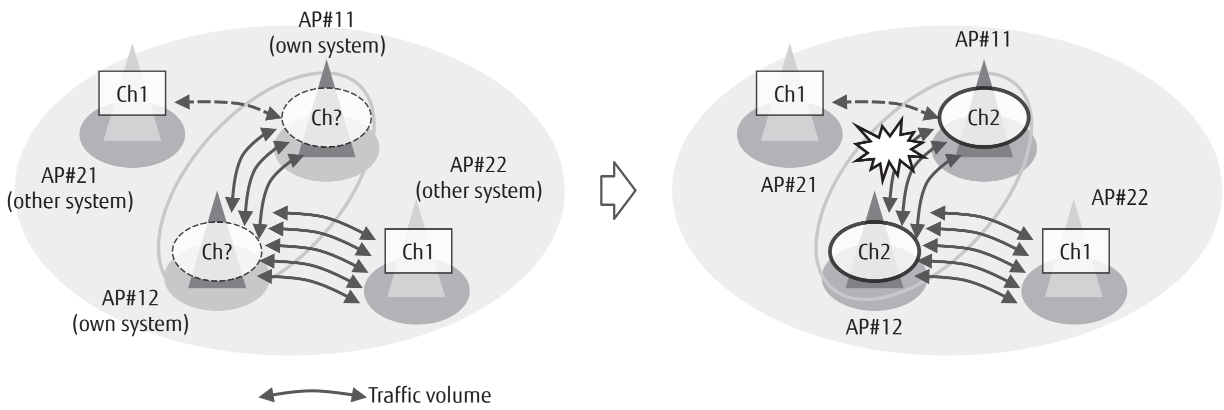

Figure 3
Channel allocation by existing technology (based on signal strength).

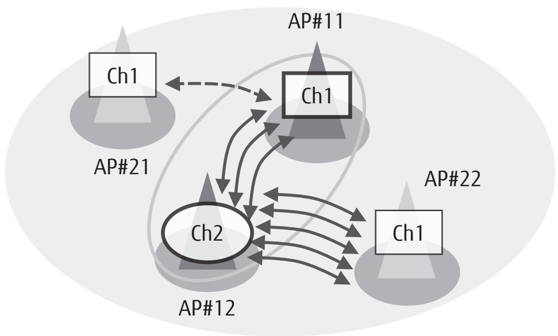

Figure 4
Channel allocation by proposed technology (based on the amount of interference).

the interference within one's own system. It then measures the time ratio of radio use (channel occupancy ratio) of one's own system and that of other systems and searches for a channel combination that minimizes interference (**Figure 4**). To perform this search, we appropriated a previously developed high-speed search algorithm.[8), 9)]

This technique forms branches of channels in sequence starting from the AP with the largest amount of interference to create a tree of channel-combination candidates. When adding an AP to this tree sequentially, the search can be accelerated by narrowing down channel-combination candidates to only those with a small amount of system interference.

In addition, while it is normally necessary to interrupt communications of long duration when measuring channel occupancy ratio while each AP switches channels, we also developed a system to prevent this from happening. This system shares the occupancy ratio of the channels currently in use by all APs and received power from neighboring APs and uses these data to estimate the amount of interference from other channels.

We evaluated the effect of channel allocation using this technology by computer simulation. To produce a clear drop in throughput stemming from interference, we arranged nine own-system APs and nine other-system APs in a nearly overlapping configuration and set the number of candidate channels to three. On performing the simulation under these conditions, we found that throughput improved by 50% on average compared with random arrangements and by 20% compared with the existing system.

5. Efforts toward autonomous operation

This section introduces our efforts in developing technology for automatically finding solutions so that wireless network managers do not have to expend energy in surveying signal conditions and tackling interference. It also describes our standardization activities in relation to this technology.

5.1 Spatial signal analysis technology

Faults that occur in a wireless network such as non-arrival of signals or interference can generally be tied to the location used by terminals or APs. The local shielding of signals by the installation of racks, production equipment, etc. or interference caused by carried-in terminals outside the scope of management constitute faults that were not taken into account when constructing the wireless network. In such a case, the locations where such faults are occurring must be identified by an on-site inspection.

For this purpose, we developed technology for automatically performing signal inspections by installing terminals for acquiring signals (signal probes) within the area targeted for measurements and analyzing those measurements on a server (**Figure 5**). A signal probe is a device that obtains detailed signal information of a targeted area. The analysis server, meanwhile, performs integrated analysis of high-granularity signal information obtained from the signal probes to estimate terminal distribution, traffic distribution, etc. in the target area and detect faults, infer causes, and identify the positions where those faults are occurring. Additionally, using the signal simulation technology described in section 3, this technology estimates the effects of implementing measures such as removing obstacles and changing AP placement.

An example of a screen displaying the results of analysis is shown in **Figure 6**. In this example, the screen shows a drop in throughput in the left half of the room and indicates that shielding produced by obstacles is the cause. Also displayed is an effect index for each of the two measures shown. In the case that changing AP placement (measure 1 with the largest effect) is difficult, the wireless network manager can select and implement a more suitable option such as removing obstacles (measure 2).

5.2 Standardization activities toward wireless network stabilization at manufacturing sites

Manufacturing sites operate a mixture of applications such as quality management, environment management, work support, device control, and safety management, each with its own communication requirements. These applications have come to be added and operated in a stepwise manner for individual facilities and processes without consideration of signal interference. As a result, the problem of mutual interference among wireless signals and of failure to satisfy communication requirements has begun to occur.[10)]

With the aim of achieving stable wireless communications even in an environment with a mixture of wireless systems and promoting the use of ICT at manufacturing sites, the Flexible Factory Partner Alliance (FFPA) was formed. The FFPA initially consisted of OMRON, Advanced Telecommunications Research Institute International (ATR), Sanritz Automation, National Institute of Information and Communications Technology (NICT), NEC, Murata Machinery, Siemens, and Fujitsu.[11)] Its main activities are formulating standards for the smart resource flow (SRF) wireless

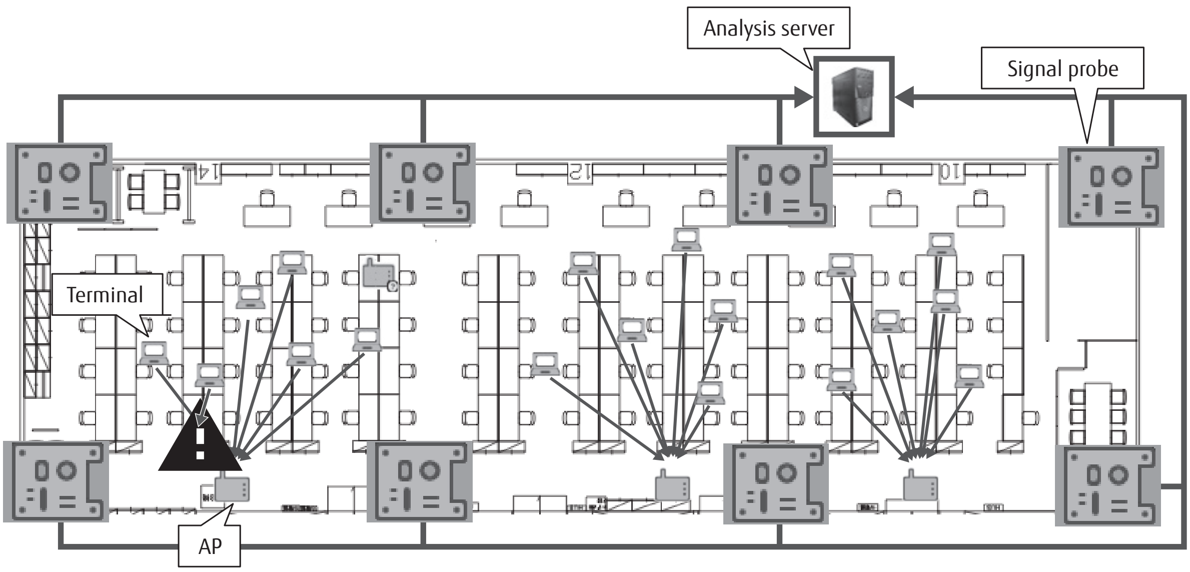

Figure 5
Typical system configuration of spatial signal analysis technology.

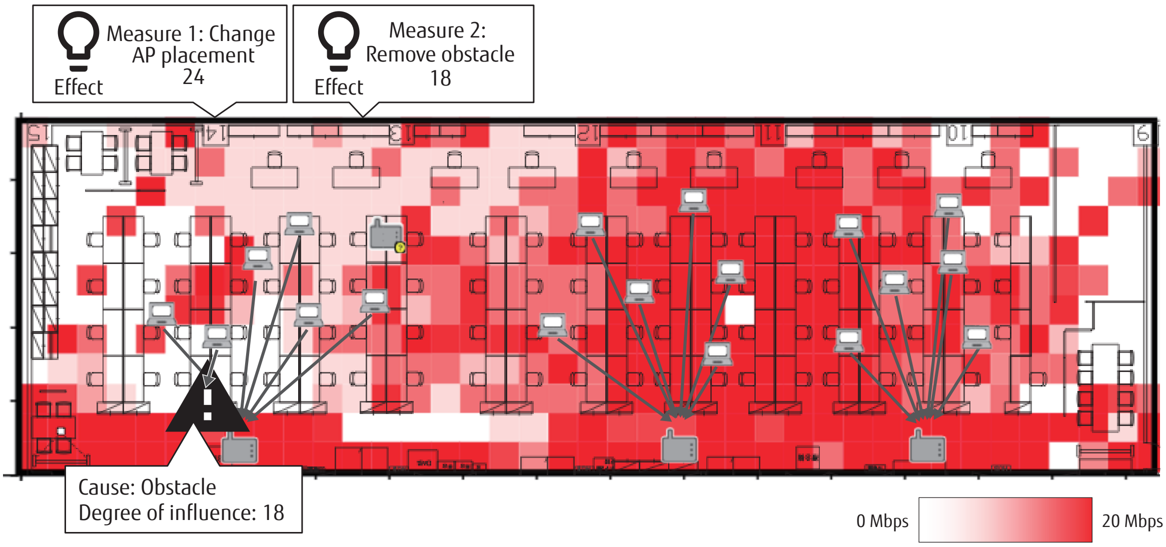

Figure 6
Example of analysis screen of spatial signal analysis technology.

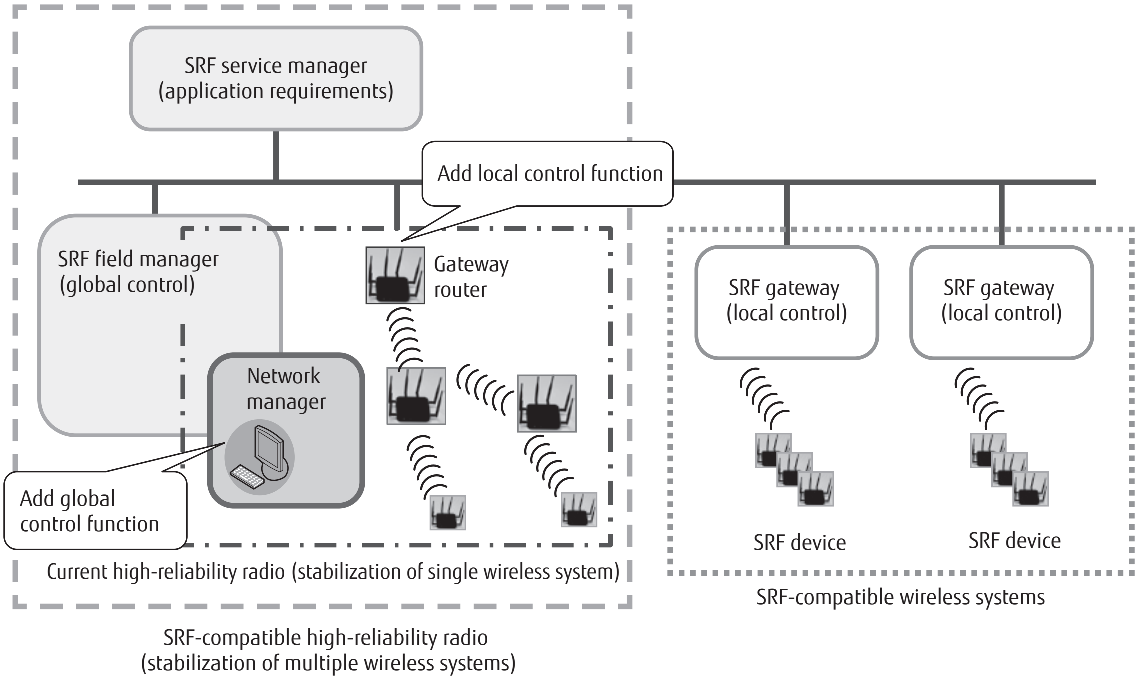

Figure 7
Stabilization of multiple wireless networks by SRF wireless platform.

platform and promoting its expanded use.

The SRF wireless platform being standardized at FFPA aims to achieve autonomous stabilization through cooperative control of radio resources (frequency, time, space). It adopts a hybrid system consisting of a global control function and local control function. The global control function notifies each wireless system of a control policy taking into account the entire wireless environment and application requirements. This function runs under the SRF field manager that manages the wireless network (**Figure 7**).[12] The local control function runs under an SRF gateway and deals autonomously with local changes in the wireless environment within the range of the aforementioned control policy.

Fujitsu is developing a high-reliability wireless solution[2] to simplify connections in a single wireless network at a manufacturing site. The aim here is to achieve stable operations in an environment with a mixture of wireless systems by incorporating SRF functions while participating in FFPA and engaging in standardization activities.

6. Conclusion

This paper introduced automatic design technology, interference control technology, and our efforts toward autonomous operation as operation technologies for high-reliability wireless networks essential to achieving CPS. These technologies are expected to enable the construction and stable operation of high-reliability wireless networks even by wireless network managers without advanced expert knowledge.

The availability of new wireless technologies such as 5G will no doubt facilitate the spread of CPS, but they are also expected to increase the number of problems in construction and operation. Fujitsu Laboratories is committed to developing technologies that will enable anyone to easily enjoy the benefits of CPS such as wireless network technology that can autonomously prevent problems from occurring before the fact.

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