Multi-radio Proactive Control Technology (Cradio®): A Natural Communication Environment where Users Do Not Need to Be Aware of the Wireless Network

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Abstract

To provide a natural communication environment where users do not need to be aware of the wireless network, we are researching and developing Cradio®—a set of multi-radio proactive control technologies that combines three advanced and coordinated technology groups: wireless sensing/visualization, wireless-network-quality prediction/estimation, and wireless-network dynamic control. This article describes the Cradio technology suite and our vision for the creation of a natural communication environment by combining these technologies with various social systems.

Keywords: Cradio®, multi-radio proactive control technologies, wireless communication

1. The prospects of wireless networks

1.1 Increasing communication volume and diversifying communication requirements

The concept of the Innovative Optical and Wireless Network (IOWN) has been proposed by NTT as a model for future implementation of networks [1]. The role of wireless communication is increasing dramatically in all aspects of our lives due to the growing volume of smartphone traffic and the development of Internet of Things (IoT) technology used to connect a variety of diverse objects to the Internet. It is therefore predicted that the volume of wireless communication will continue to increase. According to ITU-R[*1] Report M.2370, mobile data traffic will reach 5016 EB/month in 2030, about 80 times higher than in 2020 [2]. In particular, the volume of machine-to-machine communication, which correlates with IoT, is expected to increase by about 124 times (622 EB/month). This shows that in addition to the increase in communication volume, there will also be greater diversity in the types of wireless terminals and usage patterns of wireless communication. Mobile communication will not just be used for smartphones but also for remotely controlling automated vehicles and drones and exchanging ultra-high definition video. This diversification of wireless terminals and usage patterns means that it is important to provide wireless network coverage not only in urban areas where the population is concentrated but also in suburban and rural areas. Therefore, we must respond to the

*1 ITU-R: The Radiocommunication Sector of the International Telecommunication Union (ITU).

increasingly diverse requirements for wireless communication quality suitable for various forms of use.

1.2 Diversification and increased frequency of wireless networks

To address these needs, studies are underway to develop various wireless communication standards. For mobile cellular communication, commercial fifth-generation mobile communication system (5G) services were launched in 2020, and progress is now being made in the research and development of 6G technology [3]. In addition to high-speed and large-capacity communications, low-latency and highly reliable communications, and multiple connections that exceed those of 5G, 6G includes new requirements that were not considered in 5G. There are also growing expectations for the use of private 5G, which enables the flexible deployment of private 5G systems within the buildings and premises of diverse entities such as businesses and local government bodies according to the needs of individual regions and industries [4]. In wireless local area networks (LANs), IEEE*2 802.11be is being standardized as the successor to the IEEE 802.11ax wireless communication standard, which is the technology behind Wi-Fi 6. When it finally comes out, IEEE 802.11be will support not only high-speed transmission with a maximum communication rate of 46 Gbit/s but also additional features such as multiple access points [5]. Development of the IEEE 802.11ay standard for WiGig (Wireless Gigabit) networks is also underway as a successor to IEEE 802.11ad, which uses the 60-GHz band [6]. For low-power wide-area (LPWA) networks, various demonstration experiments are being conducted with the aim of implementing Wi-Fi HaLow™ (IEEE 802.11ah), which is a wireless communication standard for IoT applications that also supports video transmission [7].

With developments such as these, the use of diverse wireless communication standards such as public cellular, private cellular, wireless LAN, and LPWA networks is going to become more widespread. These wireless communication standards use a variety of frequency bands ranging from 1 GHz to several tens of GHz, and studies related to 6G are even considering the use of frequencies above the 100-GHz band and into the THz band [3]. Although these high-frequency bands support higher communication bandwidths, their coverage areas are smaller due to increased radio-wave propagation losses. Therefore, to properly handle user requirements that change from time to time, from location to location, and from one application to the next, it is essential to properly use complex wireless networks that support a mixture of different wireless communication standards across a wide range of frequency bands with different propagation characteristics.

NTT aims to provide a natural communication environment where users do not need to be aware of how they are using wireless networks because they are always provided with the best possible communication environment to suit their ever-changing needs and radio-wave conditions in their current location. As a constituent part of IOWN [1], we are working on the research and development of Cradio®, a set of multi-radio proactive control technologies.

2. Cradio® (multi-radio proactive control technologies)

We designed Cradio to keep up with the constant evolution of user requirements and radio-wave conditions so that a natural communication environment can be continuously provided without users having to be aware of how they are using the wireless network. It is broadly composed of the following three technology groups (**Fig. 1**).

(1) **Understanding (wireless sensing/visualization):** Visualization of real-world conditions by wireless state measurement/visualization, wireless sensing, etc.

(2) **Prediction (wireless-network-quality prediction and estimation):** Prediction and estimation of constantly changing wireless communication quality

(3) **Control (wireless-network dynamic design/control):** Design of physical layouts in accordance with the local environment and requirements, derivation of optimum wireless parameters, dynamic control of network parameters and resources, etc.

By advancing these three wireless technology groups and linking them in real time, we aim to keep abreast of constant changes in radio-propagation conditions and the needs of users to provide a natural communication environment where users do not have to be aware of how they are using wireless networks.

With these three technology groups, Cradio has three means of addressing each of the issues that are liable to make it difficult for users to communicate comfortably at any time and in any location (**Fig. 2**). Wireless sensing/visualization technology addresses

*2 IEEE: The Institute of Electrical and Electronics Engineers

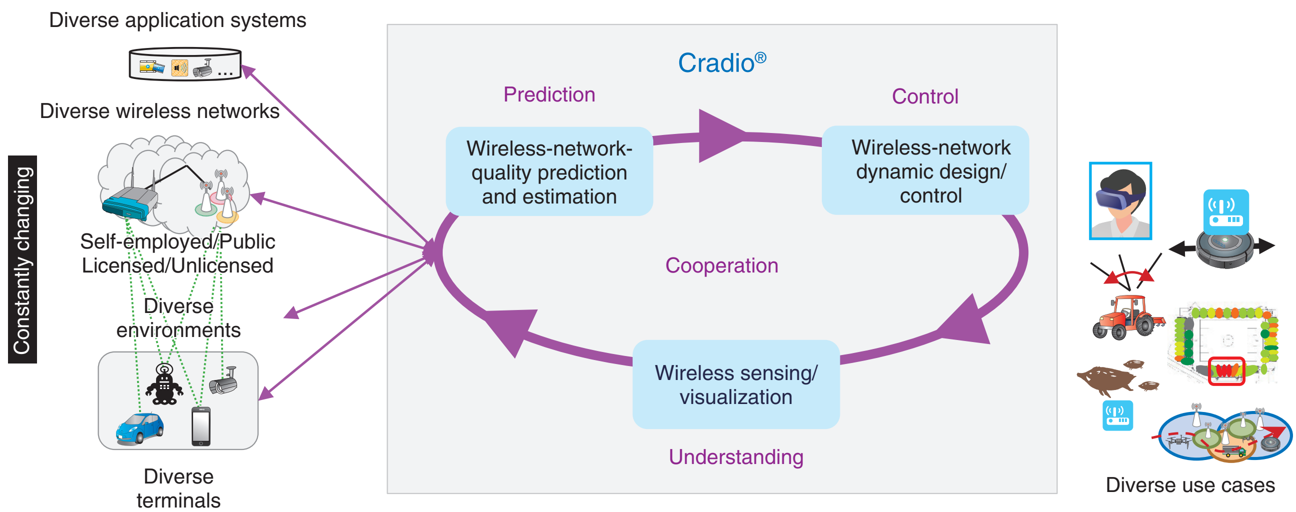

Fig. 1. Cradio concept.

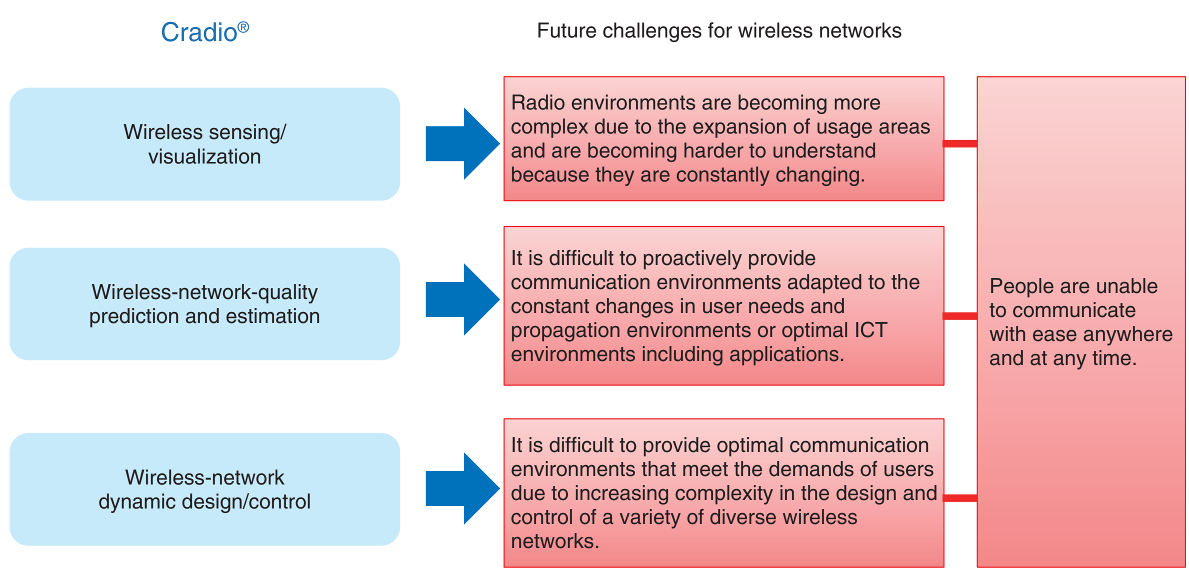

Fig. 2. How Cradio's technologies address future challenges in wireless networks.

the increasing complexity of the radio environment caused by the expansion of usage areas and the continuous fluctuations of these environments that are making them harder to understand. Wireless-network-quality prediction and estimation addresses the difficulty of proactively providing communication environments adapted to constant changes in user needs and propagation environments and optimal information and communication technology (ICT) environments including applications. Wireless-network dynamic design/control addresses the difficulty of providing optimal communication environments due to increasing complexity in the design and control used in a variety of diverse networks. These three wireless technology groups are explained below.

2.1 Understanding: Wireless sensing/visualization

Wireless sensing/visualization technology (**Fig. 3**) collects and analyzes information from various

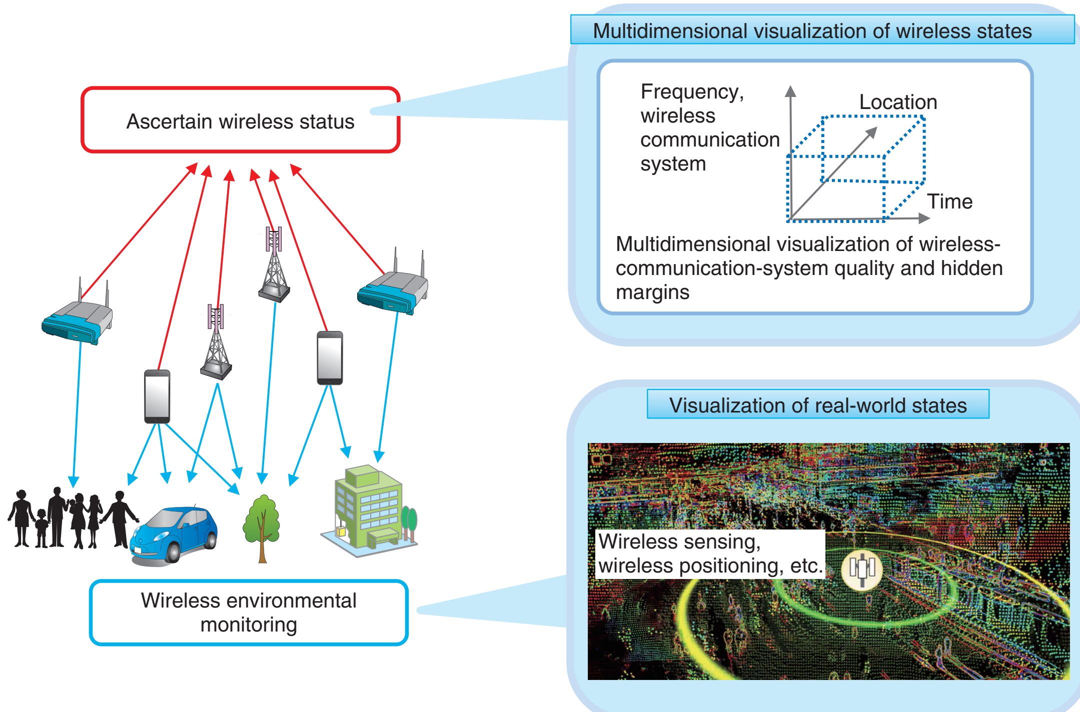

Fig. 3. Understanding – Wireless sensing/visualization.

wireless devices in various wireless communication systems to ascertain and visualize the status of wireless communication systems with regard to multiple dimensions, including frequency, method, location, and time. This makes it possible to clarify the communication quality of wireless systems, find hidden margins, and ultimately improve the efficiency of radio-wave utilization.

By using radio-communication technologies, such as wireless sensing and wireless positioning, it is possible to ascertain and visualize the real-world conditions around wireless devices. Therefore, it should be possible to quantify the position and state of everything that affects a wireless network. These technologies create an image of the real world that is important for ensuring the quality of wireless communication. This makes it possible to understand and visualize diverse environmental factors that affect wireless communication quality, including non-communication areas in wireless communication systems. It can also be expected to create added value as a new social infrastructure.

With the technology that we have used for ascertaining and visualizing the state of wireless LANs, it became possible to check the quality of a wireless LAN in real time [8]. In addition, wireless-LAN sensing technology [9] makes it possible to ascertain the impact of the surrounding environment on wireless-communication quality and create added value for wireless communication systems. We are currently working to expand the range of target wireless systems on the basis of these technologies and make further enhancements to these technologies.

2.2 Prediction: Wireless-network-quality prediction and estimation

Wireless-network-quality prediction and estimation technology executes deep learning on the basis of information obtained from wireless sensing and visualization technology to predict and estimate the quality of wireless communication, which changes from moment to moment in accordance with the surrounding environment and terminal position [10], thereby facilitating proactive optimization on the basis of future conditions (**Fig. 4**). The quality of wireless communication is affected by the radio-propagation environment between transmitters and receivers and varies in accordance with the usage conditions (resource availability) of the wireless communication system. Since these conditions

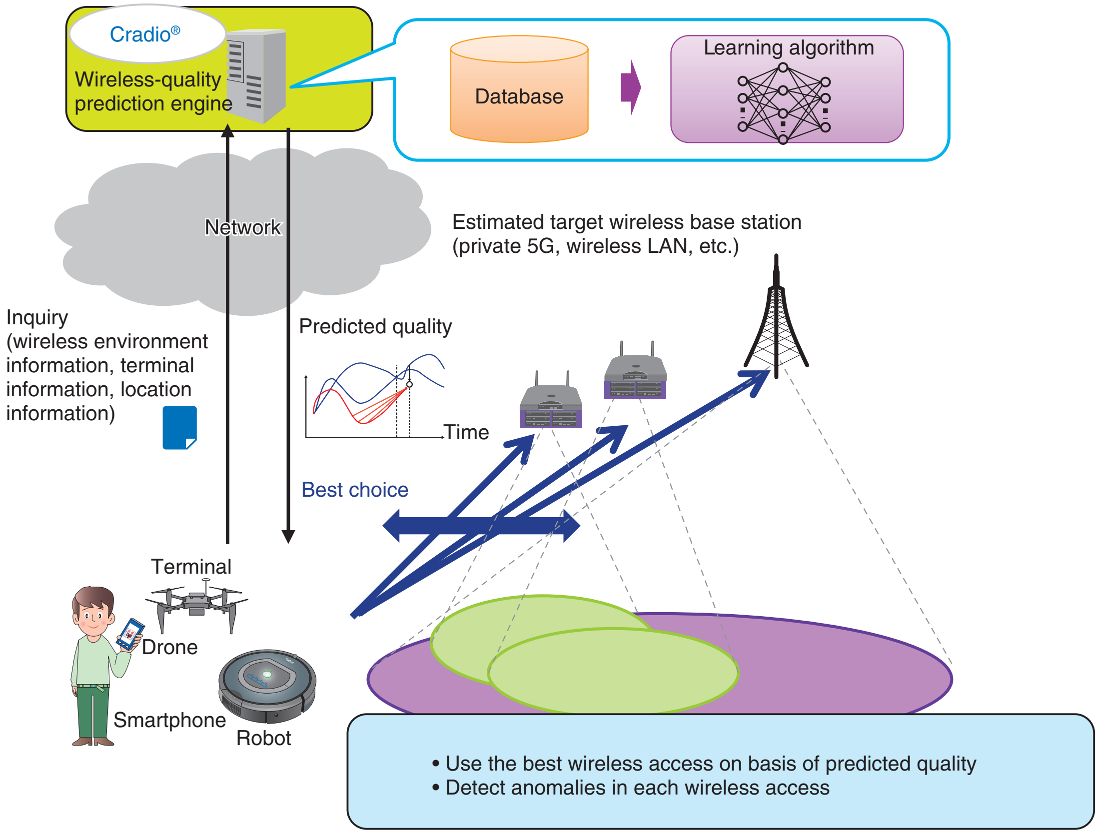

Fig. 4. Prediction – Wireless-network-quality prediction and estimation.

change from time to time, this prediction and estimation of wireless communication quality is not easy to do. With the above-mentioned wireless sensing and visualization technology, it is possible to ascertain and visualize the status of wireless communication in multiple dimensions on the basis of information collected from various devices and ascertain and visualize the real-world conditions surrounding wireless devices that affect the quality of radio communication. As a result, it should be possible to predict and estimate communication-quality parameters for each location, time period, and radio communication method with unprecedented accuracy. This will make it possible to make advance network-environment preparations in accordance with application requirements, avoid deterioration of communication quality and breaks in communication, and automatically select networks to connect to. Our aim is to provide proactive communication services that always deliver high quality of experience and quality of service.

We have conducted demonstration trials to predict the quality of communication between a cellular system and broadband wireless access in the control of self-driving agricultural machinery, which was able to execute network switching control to connect to a suitable network while continuing to provide the required communication quality [10]. We are currently investigating the enhancement of techniques for predicting and estimating the quality of general-purpose wireless networks by combining the various types of information mentioned above.

2.3 Control: Wireless-network dynamic design/control

In wireless-network dynamic design/control technology, on the basis of communication quality information obtained from wireless-network-quality prediction and estimation, we are carrying out switching/cooperation control of wireless-network dynamic configuration and switching/cooperation control of multiple wireless networks and control/optimization for the wireless connection of terminals (**Fig. 5**). As well as the optimization of various wireless parameters, this consists of comprehensive wireless-network

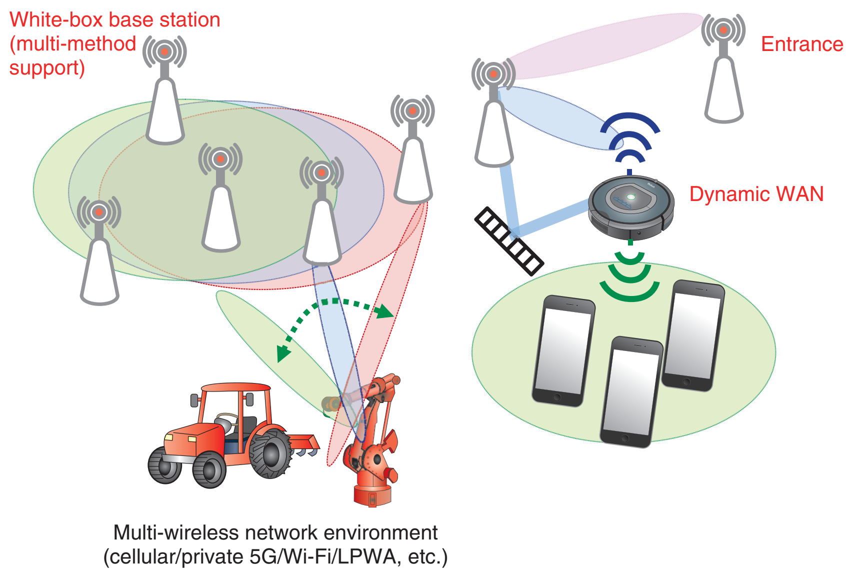

Fig. 5. Control – Wireless-network dynamic design/control.

design optimization and control measures such as the dynamic configuration of multi-radio networks with white-box wireless base stations that support multiple wireless communication standards, modification of the physical location and antenna direction of wireless base stations, and dynamic configuration of wide area network (WAN) entrances to adapt to these changes. Dynamic control can be considered not only for wireless networks but also for radio-propagation environments using equipment such as intelligent reflectors. This will make it possible to provide a world where wireless networks can be dynamically prepared wherever and whenever they are needed, facilitating a departure from the presumption of pre-prepared communication environments using conventional fixed wireless base-station locations and specified wireless communication standards. Using these technologies, our aim is to proactively and automatically configure optimal wireless networks to accommodate ever-changing user requirements and radio-wave conditions. This will lead to wireless networks that operate more efficiently and consume less power.

On the basis of wireless-resource dynamic control technology for wireless LANs that we have previously studied [11], we are working on practical technologies for the expansion and technical enhancement of target wireless systems, dynamic control of base-station placement (which have hitherto been fixed) [12], and implementation of distributed intelligent reflectors [13].

3. Cradio's potential for providing a natural communication environment

With Cradio's multi-wireless proactive control technology, it is possible to keep up with the constant changes of user needs and radio-propagation conditions through the advanced combination of wireless technologies such as the acquisition and visualization of diverse information in wireless networks, prediction and estimation of wireless-network transmission quality, and dynamic design and control of wireless networks. Cradio can also collaborate with various social systems and applications to create a natural communication environment where users do not need to be aware of the wireless network. By cooperating with various application systems outside the wireless layer, Cradio optimizes the wireless network in accordance with the status of applications that are in use and optimizes applications in accordance with the status of the wireless network (**Fig. 6**).

For example, by cooperating with and using information from social systems such as weather information systems and demographic systems involving various types of sensors and video information from cameras, we can expect to improve the accuracy of quality prediction/estimation and acquisition/visualization of information from wireless networks, including information about local conditions, such as

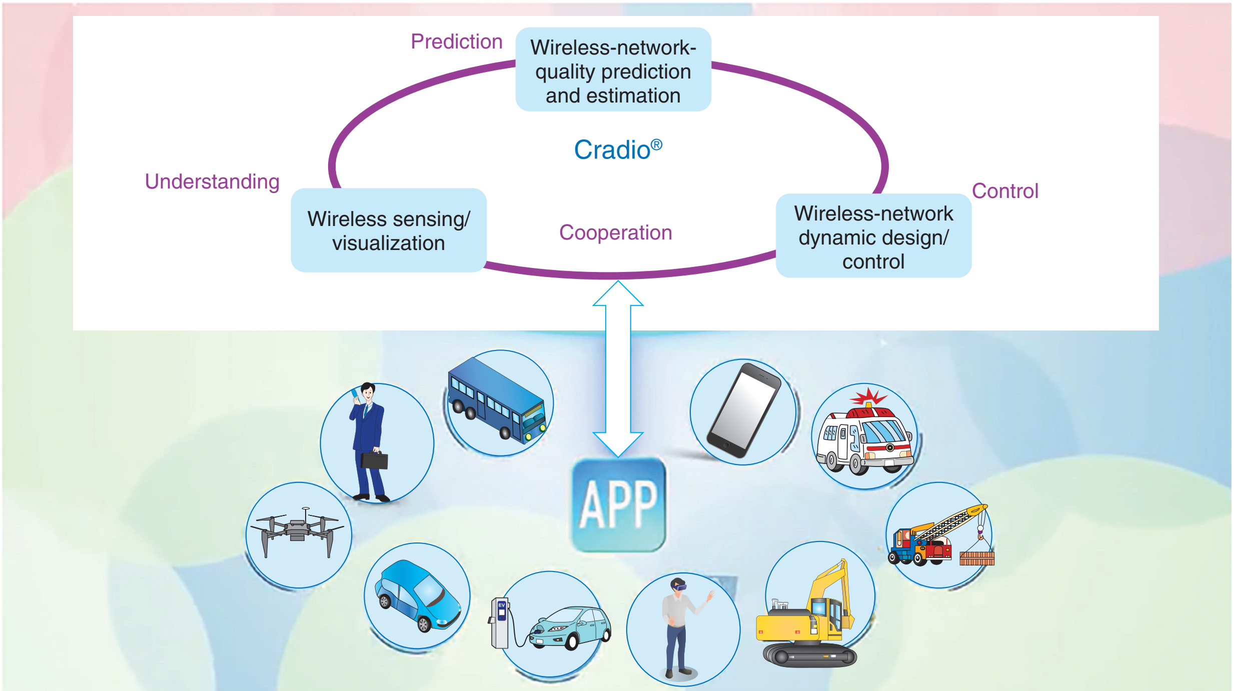

Fig. 6. Coordination of multi-radio proactive control technology (Cradio) with various applications and social systems.

rainfall, that can affect radio communication (especially at high frequencies), and the state of use of wireless communication systems (available wireless resources), and to use this information for the design and control of wireless networks [14]. In the above-mentioned example of autonomous vehicles, by using Cradio to predict and estimate wireless network quality in cooperation with automated driving management systems, it is possible for autonomous vehicles to select routes and adjust their driving speeds in accordance with the current quality of wireless communication. Video systems needed for the management of autonomous vehicles should be able to maintain the required video quality by dynamically adjusting the video codec rate. Therefore, all types of systems can be operated in a more advanced and flexible manner by cooperating with diverse social systems to obtain input information that can be used by Cradio and by cooperating so that information obtained with Cradio can be used outside the radio network layer.

Cradio's wireless technologies can provide higher value by coordinating with various systems and applications. We are currently conducting research and development aimed at implementing Cradio to provide wide-ranging value.

4. Future prospects

We described various components of Cradio and the natural communication environment that Cradio can provide through cooperation with diverse systems and applications. With the arrival of IOWN around 2030, we will continue to promote research and development aimed at implementing Cradio.

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He received the Best Paper Awards from IEICE in 2011, 2016, and 2020. He was honored with the IEICE KIYASU Award in 2016. He received Radio Achievement Award from ARIB in 2020 and the IEEE Standards Association's Outstanding Contribution Appreciation Award for the development of IEEE 802.11ac-2013 in 2014. He is a senior member of IEICE and a member of IEEE.