Efficiently Accommodating High-frequency-band Wireless Systems by Using Analog Radio-over-fiber

Kota Ito, Mizuki Suga, Yushi Shirato, Naoki Kita, and Takeshi Onizawa

Abstract

Large-capacity wireless transmission is possible with high-frequency-band wireless systems, but it is necessary to deploy wireless base stations at high density. Under the assumption that the number of wireless systems will increase to meet diversifying needs, the number of wireless base stations to be installed is expected to increase dramatically. At NTT Access Network Service Systems Laboratories, we propose a system configuration that uses analog radio-over-fiber (RoF) technology to enable multiple high-frequency-band wireless systems to share wireless equipment for drastically reducing the number of wireless base stations and their operating loads. This system configuration and its fundamental technology, namely, our remote-beamforming technology, are introduced in this article.

Keywords: analog RoF, beamforming, efficiently accommodate

1. Introduction

To further expand wireless-transmission capacity, it is effective to use radio waves in the high-frequency band (such as millimeter waves[*1]), which can secure a wide bandwidth. However, the propagation distance of radio waves becomes shorter as their frequency becomes higher. Therefore, to cover a wide area with a high-frequency-band wireless system, it is necessary to install wireless base stations with high density. In the past, wireless base stations had to be installed for each wireless system. Accordingly, as high-frequency-band wireless systems diversify to meet diversifying needs, an enormous number of wireless base stations will need to be installed. To drastically reduce the number of wireless base stations to be installed and effectively manage their operation, we propose a system configuration that allows multiple wireless systems to share a wireless base station. This system configuration and our remote-beamforming technology—which is indispensable when accommodating high-frequency-band wireless systems with this system configuration—are introduced in this article.

2. Separation of functions and simplification of base stations by using analog RoF

Analog radio-over-fiber (RoF)[*2] technology modulates the intensity of an optical signal with a wireless signal and transmits the optical signal in the form of a wireless signal via an optical fiber. The transmitted optical signal is then subjected to optical-to-electrical (O/E) conversion[*3] to extract the original wireless

*1 Millimeter wave: A radio (wireless) wave with a very short wavelength of 1 to 10 mm and frequency of 30 to 300 GHz.

*2 RoF: A technology for transmitting the waveform information of wireless signals via optical fiber. Analog RoF converts the waveform into an analog signal as is, and digital RoF converts the waveform to a digital signal before transmitting via optical fiber. Compared to digital RoF, analog RoF does not require A/D (analog-to-digital) or D/A (digital-to-analog) conversion, and the required optical transmission bandwidth can be narrowed.

*3 O/E conversion: A photodiode is generally used to convert an optical signal into an electrical signal.

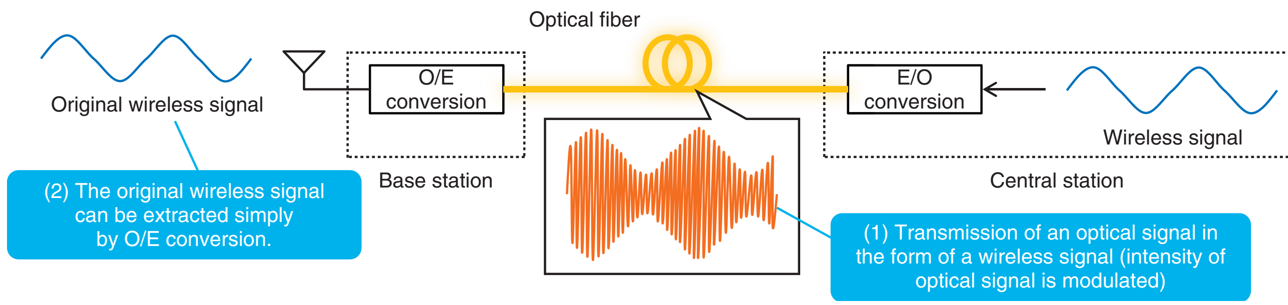

Fig. 1. Analog RoF.

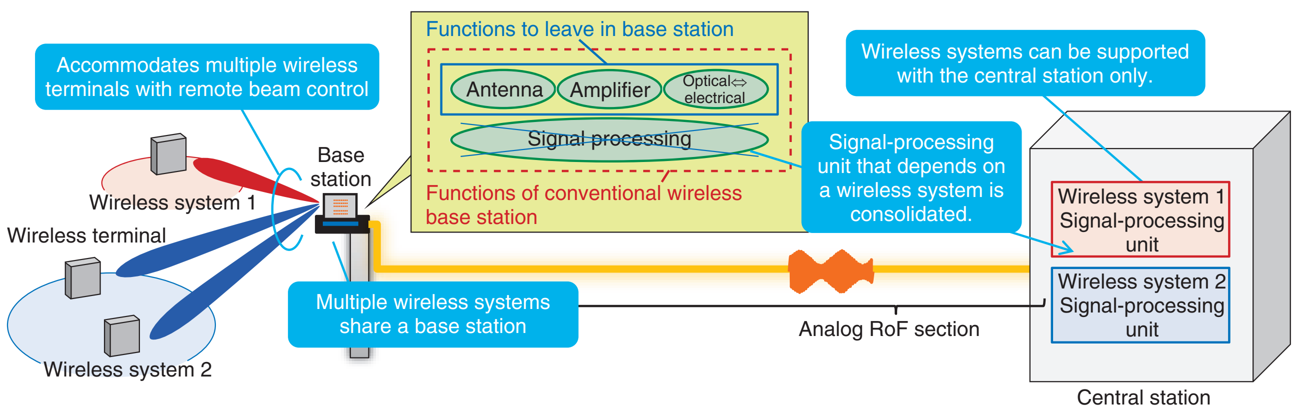

Fig. 2. Function consolidation by using analog RoF.

signal (**Fig. 1**).

By applying analog RoF, the functions of a conventional wireless base station can be separated into two locations, i.e., a central station (accommodating the signal-processing unit) and the base station (accommodating the antenna unit) (**Fig. 2**). Conventional wireless base stations have multiple pieces of equipment and functions: antenna, amplifier, electrical-to-optical (E/O) and O/E conversion, and signal processing. By applying analog RoF to consolidate signal processing at the central station, it is possible to simplify the functions of the base station. As a result of such consolidation, installation flexibility and economic efficiency will improve by reducing the size and power consumption of base stations.

By having only signal processing (which depends on the wireless system) be in the central station, the common functions that do not depend on the wireless system can be left at the base station. Therefore, it is possible for multiple wireless systems to share a base station as long as its frequency range is compatible with the station's antenna and amplifier. New wireless systems can be installed or renewed, and operations can be carried out on the central-station side only; thus, efficient deployment and operation of wireless systems will become possible. It is also expected that the number of wireless base stations and operational costs can be drastically reduced.

3. Remote-beamforming technology

Beamforming*4 is an essential technology for high-frequency-band wireless systems—which can only achieve short propagation distances. For conventional

*4 Beamforming: A technology for electrically controlling the directivity of a wireless signal (beam) by using an array antenna with multiple arranged antenna elements. By controlling the phase of the radio waves transmitted and received by each antenna element, it is possible to enhance the transmission of a radio wave in a specific direction ("transmitting beam") and to receive and enhance the radio wave arriving from a specific direction ("receiving beam").

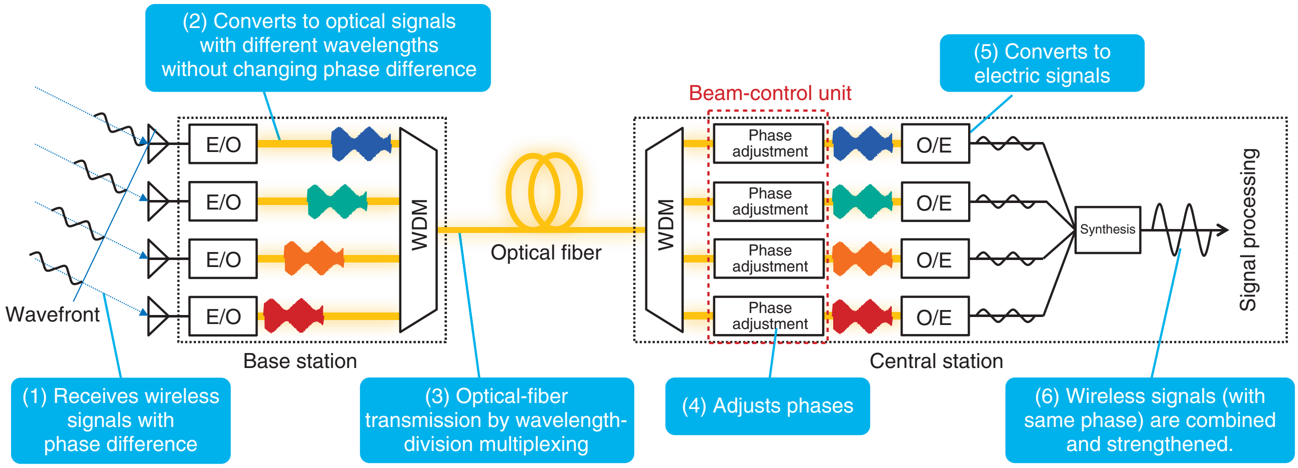

Fig. 3. Remote-beamforming technology (receiving side).

wireless base stations, beamforming is executed by their signal-processing units. When functions are separated and base stations are simplified by applying analog RoF, the problem of how to carry out beamforming at base stations that do not have signal-processing units arises. Therefore, we previously proposed and have been investigating a technology called remote beamforming that can remotely control the beam formed at the base station from the central station [1, 2].

Our remote-beamforming technology is explained with the example of using a receiver in **Fig. 3**. When a wireless signal arrives at a base station with multiple antenna elements, each element receives a wireless signal with a phase difference. While this phase difference is maintained, the wireless signals received by each antenna element are converted into optical signals with different wavelengths and transmitted to the central station via optical fiber by wavelength-division multiplexing (WDM). The central station de-multiplexes the wavelength-multiplexed signals with each wavelength, adjusts the phases of these optical signals, converts the optical signals to electrical ones (O/E conversion), and combines the electrical signals. The original wireless signals are then combined in a state of matching phases and strengthened to form a receiving beam in the direction of the arrival of the wireless signals. Although the optical signals are phase-adjusted in **Fig. 3**, it is also possible to adjust the phases of the electrical signals after O/E conversion and synthesize the signals. The transmitting beam can be formed on the basis of the same principle. At this time, the base station only performs O/E and E/O conversions of the received signal and does not require any control.

There are two conventional remote-beamforming technologies: one assigns a separate optical fiber (a separate core in the case of multi-core fiber) to each antenna element [3] and the other [4, 5] uses chromatic dispersion[*5] to switch the beam direction by changing the wavelength assigned to each antenna element. By overcoming the problems of these conventional technologies (by fixing the wavelength assigned to each antenna element), our remote-beamforming technology has four advantages: (i) only one optical fiber (core) is used; (ii) optical-fiber-distance information is unnecessary; (iii) control of the optical filter at the base station is unnecessary; and (iv) the format of the wireless signal is unrestricted even if a high-frequency band and long-distance optical fiber are used.

Our remote-beamforming technology not only ensures communication quality of high-frequency-band wireless systems but also enables a base station to simultaneously accommodate multiple wireless terminals by executing space-division multiplexing (SDM). Since the beam direction can be controlled remotely, it is not necessary to physically adjust the antenna direction when configuring the base station.

We demonstrated our remote-beamforming technology in a receiving system at the NTT R&D Forum

*5 Chromatic dispersion: A phenomenon by which propagation time differs because the speed of light propagating in an optical fiber varies according to the wavelength of the light. It occurs because the refractive index of an optical fiber also depends on the wavelength.

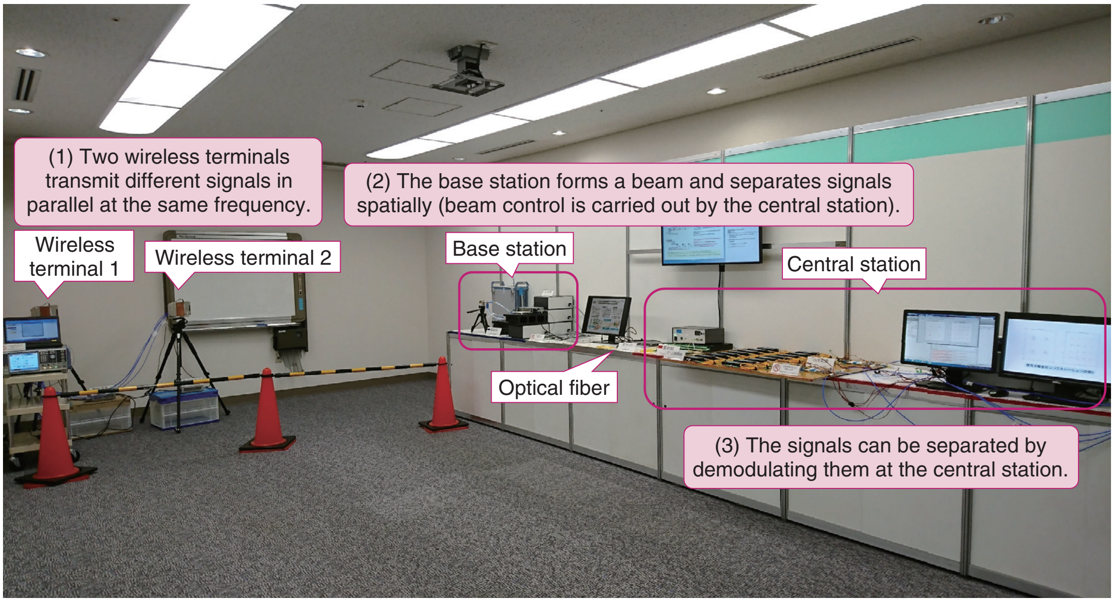

Fig. 4. Setup of exhibition.

2019 (**Fig. 4**).

4. Future outlook

We will improve wavelength-utilization efficiency by improving our remote-beamforming technology and work with researchers of optical communications to study practical applications of this technology.

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