Power-over-Fiber for Remote Antenna Units in 5G/6G Networks

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***Abstract*—This paper introduces power-over-fiber technologies using various optical fibers as a means of supplying electric power to drive a remote antenna unit in 5G/6G networks. This paper also discusses the latest trends and future prospects of power-over-fiber technologies.**

***Keywords*—power-over-fiber (PWoF), radio-over-fiber (RoF), remote antenna units, double-clad fibers, mobile communications**

I. Introduction

With the 5th generation mobile communication system (5G) requires a low latency communication environment and an increase in the number of simultaneous connections to a variety of wireless terminals [1],[2]. Radio-over-Fiber (RoF), in which radio-frequency (RF) signals (wireless signals) are converted into optical signals and transmitted over optical fibers, plays an important role in improving transmission speed. As RoF enables broadband and low-loss transmission of wireless signals to distant remote antenna units (RAUs), it will be indispensable for future wireless communications. Internet of Thing (IoT) is expected to expand its range of applications as the number of simultaneous connections to wireless terminals improves. By connecting objects that have not been connected to the Internet to a network via RAUs, IoT is expected to bring about major changes in infrastructure, factories, agriculture, and other areas. Thus, future wireless communications will require a huge number of RAUs in various environments.

Power-over-fiber (PWoF) is an essential technology that can drive remote communication equipment by transmitting optical power through optical fibers [3],[4]. If high-speed data and power can be simultaneously transmitted into a single optical fiber, it will be possible to drive RAUs without any external power supply systems such as public power lines and large-scale batteries. As a result, the installation, management, and control of RAUs will be expected to be greatly simplified.

This paper describes PWoF technologies that can simultaneously transmit data signals and power over a single optical fiber. After explaining the role of PWoF in mobile networks and introducing various kinds of optical fibers for PWoF, our recent experimental demonstration is presented. Lastly, the current status and future prospects of PWoF are described.

II. Power-over-Fiber in Mobile Networks

Fig. 1 shows the schematic view of PWoF in mobile communications. The central office (CO) and each RAUs are connected by optical fibers for RoF transmission. Currently, each RAU is supplied with power from nearby public power lines. However, if the power can be supplied using the optical fibers, the following advantages can be mentioned.

- **Backup power supply for disaster**: When a power outage occurs due to disaster such as major earthquake, RAUs are shut down and mobile services become unavailable. If PWoF can be used as a backup power source, mobile services are available even in the disaster areas, and mobile phones can be used to obtain disaster information and to confirm the safety of family.

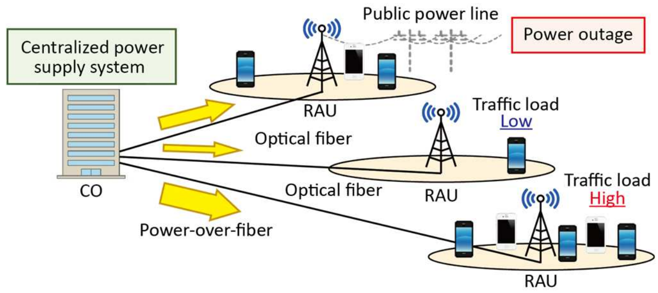

Figure 1: Schematic view of PWoF in mobile networks. CO: Central office, RAU: Remote antenna unit.

- **Power control according to mobile traffic:** Mobile traffic of each RAUs varies greatly depending on the number of users and the traffic of each user. However, current RAUs always operate with 100% power supply regardless of the traffic. In contrast, if PWoF is used, it is possible to control the power according to the traffic, and power saving in the entire mobile network is expected.

- **Centralized power management:** If power can be centrally managed at the CO, the management and control of RAUs can be greatly simplified. If the CO is equipped with an emergency power supply system or private power plant, it will be possible to drive the RAUs regardless of the environment of area where the RAU has to be installed and provide disaster-resistant mobile communications.

On the other hands, to drive a RAU without any external power supply, the required power is over 10 W and more. For this reason, the selection of the optical fiber to be used is very important. Table 1 shows the optical fibers for PWoF. Until now, PWoF using single-mode fibers (SMFs) [5], multi-mode fibers (MMFs) [6], and multi-core fibers (MCFs) [7] have been reported. However, it is difficult to achieve high-speed data transmission and over 10 W power supply simultaneously. In contrast, we have been studying PWoF using double-clad fibers (DCFs) with a double-core structure, in which the small core is surrounded by a large core. In this fiber, data signals are transmitted in the SM core and high-power feed light is transmitted in the large core, enabling simultaneous broadband and high-power power transmission over a single optical fiber. Our recent result is explained in the next Section.

III. Power-over-Fiber Using Double-Clad Fibers

When using DCFs, conventional couplers cannot be used to combine and divide between the small core and large core

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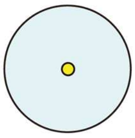
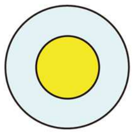
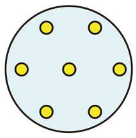
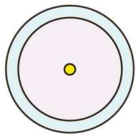
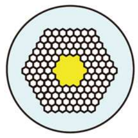
Table 1: Various types of optical fibers for PWoF.

	Single-mode fiber (SMF)	Multi-mode fiber (MMF)	Multi-core fiber (MCF)	Double-clad fiber (DCF)	Hollow core fiber (HCF)
Cross section					
Signal/Power transmission	Single core	Single core	Individual core	Signal: Small core Power: Large core	Single core
Transmission bandwidth	Broad	Narrow	Broad	Broad (Small core)	Broad
Transmission power	Low	Middle	Middle	High (Large core)	High

[8]–[10]. Therefore, in addition to customized tapered fiber bundle combiner and divider, cladding power strippers are required to prevent the leakage of high-power feed light in the inner cladding. In our experiment, a total of 150 W of feed light power was input to a 300 m DCF, and 43.7 W of electric power was transmitted. In this scheme, photovoltaic power converters (PPCs) that convert transmitted optical power into electric power also plays an important role. By using vertical epitaxial heterostructure architecture (VERHA) structure PPCs with a conversion efficiency of more than 50% [11], the high-power electric power transmission was successfully achieved. The detailed configuration and its performance are described in Ref. [10].

IV. Future Prospects

In the actual use of PWoF, it is important to improve the power transmission efficiency. In DCFs, as the loss in the large core is generally much higher than that in the small core, it is necessary to improve the loss and shift available feed light wavelength to a longer wavelength band. As a result, it is desirable to be able to transmit more than 10 W of electric power to the RAU over a few kilometers of a DCF.

In addition to DCFs, another candidate for simultaneous broadband and high-power transmission over a single optical fiber are hollow core fibers (HCFs) as shown in Table 1. Nested antiresonant nodeless fibers (NANFs) [12] and photonic bandgap fiber (PBGFs) [13] are representative HCFs and are still under active research and development. HCFs are capable of broadband transmission if single-mode signal transmission is possible in the core, and are suitable for high-power transmission because the core is air. Indeed, 1 kW power transmission experiment using a 1 km HCF has already been reported [14]. The transmission loss of HCFs has also been greatly improved in recent years, and equivalent loss has been achieved in the 1550 nm band, which is the lowest loss wavelength band for silica core optical fiber [15]. On the other hand, there are various significant issues to be solved, such as the connection with silica core fiber, bending loess, and mass production. However, it is expected that PWoF using HCFs will surpass silica core fiber in the future.

V. Conclusion

This paper describes PWoF for driving RAUs, including our recent results. In addition to the features not found in conventional power lines, PWoF is an attractive technology for future infrastructures. In PWoF, optical fibers, high-power lasers, and photoelectric conversion devices are also rapidly improving their performance. It is expected that these developments will also support the development of PWoF itself and the expansion of its application fields.

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