Evaluation of Response Time of Power-Over-Fiber for Dynamic Power Control of Remote Antenna Units in Mobile Networks

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***Abstract**: We have evaluated the response time of power-over-fiber for dynamically controlling the supplied power of remote antenna units in mobile networks. The dynamic power control function is effective for power saving of entire mobile networks. The results show that power-over-fiber has sufficient response time, which allows to use dynamic supplied power control of remote antenna units in mobile networks.*

1. Introduction

In recent development of mobile communication services, it is necessary to increase the carrier frequency of radio-frequency(RF) signals. However, higher frequency radio signals have higher transmission losses, and reduce the cell area that can be covered by a single remote antenna unit (RAU). As a result, more RAUs will be needed in the future. In addition, a smaller and simpler RAU is desirable from the viewpoints of maintenance and cost in mobile natworks. Radio-over-fiber (RoF) is an essential technology that transmits high-frequency RF data signals in optical fibers between a central office (CO) and RAU [1,2]. However, in conventional RoF-based mobile networks, optical fibers transmit only RoF data signals, and separate electric power lines are needed to drive RAUs.

Power-over-fiber (PWoF) enables us to simultaneously transmit RoF data signals as well as power required for driving RAUs into a single optical fiber [3,4]. Until now, a number of experimental demonstrations using various kinds of optical fibers have been reported. In such PWoF systems, dynamic power control of RAUs according to the entire mobile trafffic of each RAU is an attractive function, because it is always possible to minimize the power supplied to the RAU [5]. In particular, in mobile networks where multiple RAUs are collectively managed by a CO, a significant reduction in power consumption of the entire mobile network can be expected. On the other hand, it is important to evaluate the response time of power control in PWoF systems, because the dynamic power control based on the mobile traffic of each RAU requires a response time of the order of milliseconds or less.

In this study, we have evaluated the response time of PWoF for dynamic power control of RAUs in mobile networks. The overall response time of PWoF systems is determined by the modulation speed of feed light source, the transmission delay of optical fiber link length, and the response time of photovoltaic power converters (PPCs). In particular, it is well known that the response time of PPCs is much slower than that of common photo-diodes (PDs) [6]. Thus, we have measured the response time of PPCs and calculate the overall response time of PWoF to evaluate the availablity of dynamic power control.

2. RoF-based mobile network for PWoF

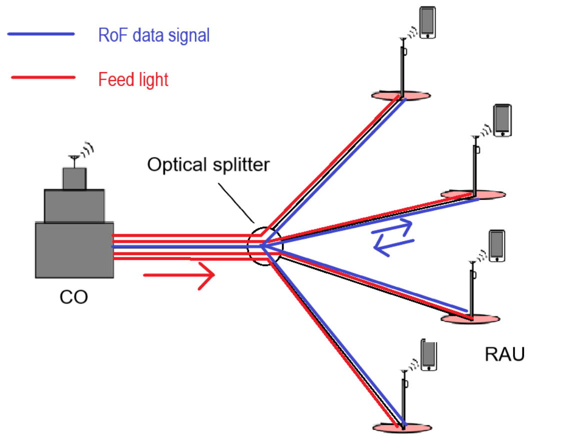

Fig. 1. Example of RoF-based mobile network for PWoF. CO: Central office, RAU: Remote antenna unit.

Figure 1 shows the example of RoF-based mobile network for PWoF. The feed light to drive RAUs is transmitted from feed light sources in the CO, and the feed light transmitted over optical fiber links connecting the CO and RAUs is converted to electrical power by a PPC in each RAU. In this scheme, the overall response time of PWoF is determined by the modulation speed of the feed light sources, the transmission delay of the optical fiber link length, and the response time of the PPC. Therefore, to evaluate the overall response time of PWoF, it is necessary to calculate these response times.

3. Experimental setup

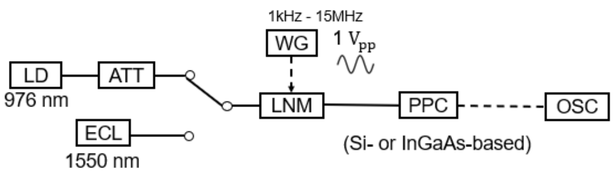

Fig. 2. Experimental setup for measuring response time of PPC. LD: Laser-diode, ATT: Attenuator, ECL: External-cavity laser-diode, LNM: $LiNbO_3$ modulator, WG: Waveform generator, OSC: Oscilloscope.

Figure 2 shows the experimental setup for measuring the response time of two commercially available PPCs. One was a silicon (Si)-based PPC. The other was an InGaAs-based PPC. The optimum operating wavelength of the PPCs were at around 980 nm and 1550 nm, respectively. To evaluate the response time in a wider frequency range, we measured and compared the relative amplitudes of a sinusoidal wave by turning the frequency of the wave instead of using a common network analyzer. As for the Si-based PPC, the wavelength of the feed light source generated by a laser-diode (LD) was 976 nm. Since the output power of the LD was high, an attenuator (ATT) was used to adjust the input power to a $LiNbO_3$ modulator (LNM) at the output of the LD. As for the InGaAs-based PPC, the wavelength of the feed light source generated by an external cavity laser-diode (ECL) was 1550 nm. Each feed light was injected into the LNM, and modulated by an electrical sinusoidal wave generated by a waveform generator (WG). After that, each modulated feed light was injected into each PPC, and converted into the electrical sinusoidal wave. The sinusoidal wave was monitored by an oscilloscope, and the frequency characteristics was measured based on the relative amplitude change as the frequency of the sinusoidal wave was varied.

4. Results

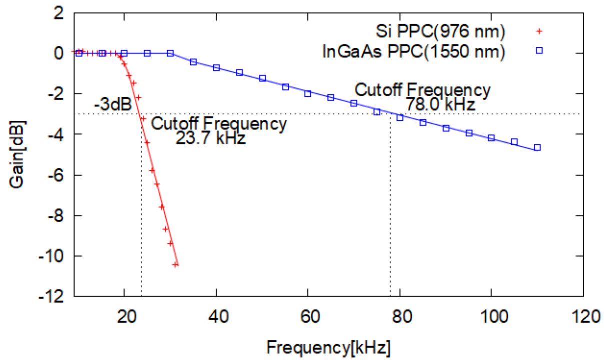

Fig. 3. Frequency characteristics of PPCs

Figure 3 shows the frequency characteristics of the PPCs we used. The cutoff frequency is defined as the frequency point at which the amplitude of the sinusoidal wave decreases by 3 dB from the output at the flat level. The cutoff frequency of the Si-based PPC was 23.7 kHz. The response time calculated from the cutoff frequency was 14.8 µs. The cutoff frequency of the InGaAs-based PPC was 78.0 kHz, and the calculated response time was 4.5 µs. The response time of the InGaAs PPC at 1550 nm is approximately 3.3 times faster than of the Si PPC at 976 nm. On the other hand, it was found that the response time of commercially available PPCs was less than 15 µs.

As for the modulation speed of feed light sources, commercially available high-power LDs (HPLDs) have been reported to have performance on the order of several tens of microseconds or less [6]. In the RoF-based mobile networks as shown in Fig. 1, the optical fiber link length is assumed to be less than 10 km. Therefore, the maximum propagation delay time in a 10 km optical fiber link is approximately 50 µs. These results indicate that PWoF is expected to be able to dynamically control the power for RAUs with a response time of less than 100 microseconds. In addition, in the previous study [4], we have presented that PWoF systems have an extremely high linear output characteristic with respect to the input power of feed light sources, and the stability of the supplied optical power. This means that PWoF provides a simpler power control than those of conventional power supply systems using metal cables.

5. Conclusion

We evaluated the response time of PWoF for dynamic power control of RAUs in mobile networks. In particular, PPC is a key device to determine the overall response time of PWoF. As a result, the overall response time of PWoF was expected to be less than 100 microseconds, which is sufficient for dynamic power control of RAUs in RoF-based mobile networks.

Acknowledgement

This work was partly supported by National Institute of Information and Communications Technology (NICT) in Japan and National Science Foundation (NSF) in USA through grants 2210343 and 2210344.

References

[1] I. A. Alimi, A. L. Teixeira, and P. P. Monteiro, “Toward an efficient C- RAN optical fronthaul for the future networks: A tutorial on technologies, requirements, challenges, and solutions,” IEEE Commun. Surveys Tuts., vol. 20, no. 1, pp. 708–769, Jan.–Mar. 2018.

[2] D. Novak at al., “Radio-over-fiber technologies for emerging wireless systems,” IEEE J. Quantum Electron., vol. 52, no. 1, Jan. 2016, Art. no. 0600311

[3] M. Matsuura, “Recent advancement in power-over-fiber technologies,” Photon., vol. 8, no. 8, pp. 335, 2021.

[4] M. Matsuura, “Power-over-fiber using double-clad fibers,” J. Lightwave Technol., vol. 40, no. 10, pp. 3187-3196, 2022.

[5] M. Matsuura, “Optically-powered radio-over-fiber systems,” in Proc. CLEO2018, SM1C.3, 2018.

[6] H. Nomoto, D. Kamiyama, N. Tajima, T. Okada, and M. Matsuura, “Evaluation of frequency response of photovoltaic power converter for controlling supply power via power-over-fiber systems,” in Proc. OWPT2019, OWPT-P-13, 2019.

[7] BWT Beijing Ltd. (https://www.bwt-bj.com/en/)