16 Gbit/s, 256 QAM Optical and Wireless Linked Fully Coherent Transmission at 28 GHz Using Small Microstrip Antennas

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Abstract *We describe a 2 Gbaud 256 QAM coherently-linked optical and wireless transmission at 28 GHz with an injection-locked carrier-frequency converter and small microstrip antennas. With this combination, 16 Gbit/s data were successfully transmitted over a 10 km SMF and 10 m wirelessly.*

Introduction

Research and development toward the realization of beyond 5G including advanced 5G [1] and 6G [2] are in active progress. A 6G radio access network (RAN) requires extremely high-speed, massive connectivity, and extremely low-latency characteristics [3]. To realize such a RAN, it is essential to develop an economical mobile fronthaul (MFH) that can deliver large-capacity data signals to multiple antennas with low latency.

As such an MFH, a coherent analogue radio-over-fibre (CA-RoF) technique is attractive. Several optical and wireless linked transmissions have already been demonstrated with a self-heterodyne detection (SHD) method, where a CW optical tone signal is transmitted with the data signal and used as a local oscillator (LO) for SHD [4-6]. The CA-RoF does not require an A/D, D/A and digital signal processor (DSP) in the optical receiver. Therefore, it is economical and low latency compared with a digital RoF system. Moreover, an intermediate frequency (IF) can be flexibly varied by changing the frequency of an optical tone signal.

On the other hand, we proposed optical and wireless linked fully coherent transmission with an injection-locked carrier frequency converter (IL-CFC) [7,8]. With this system, we transmitted a 48 Gbit/s, 256 QAM signal at 61 GHz over a 10 km single-mode fibre (SMF) and over 40 m wirelessly with large conical horn antennas (ϕ27 cm) between the transmitter and the receiver [9]. Furthermore, we clarified the major advantage of the IL-CFC which has a larger loss budget than SHD [10]. Recently, we applied this transmission method to the 28 GHz band to show that the IF frequency (wireless carrier frequency) can be easily changed. In addition, a ϕ27 cm horn antenna was replaced with a small microstrip antenna (10 cm×7 cm).

This paper describes how, by adopting small microstrip antennas and high-gain RF amplifiers in our wireless transceiver, we successfully achieved a 16 Gbit/s, 256 QAM transmission at 28 GHz over a 10 km SMF and 10 m wirelessly.

Optical and wireless linked fully coherent transmission system at 28 GHz

Figure 1 shows the configuration of our optical and wireless transmission system at 28 GHz. It is almost the same as the previous transmission system [10] except for the antennas used at both a remote unit (RU) and a user site.

At a central office, the output of a 1.5 μm LD

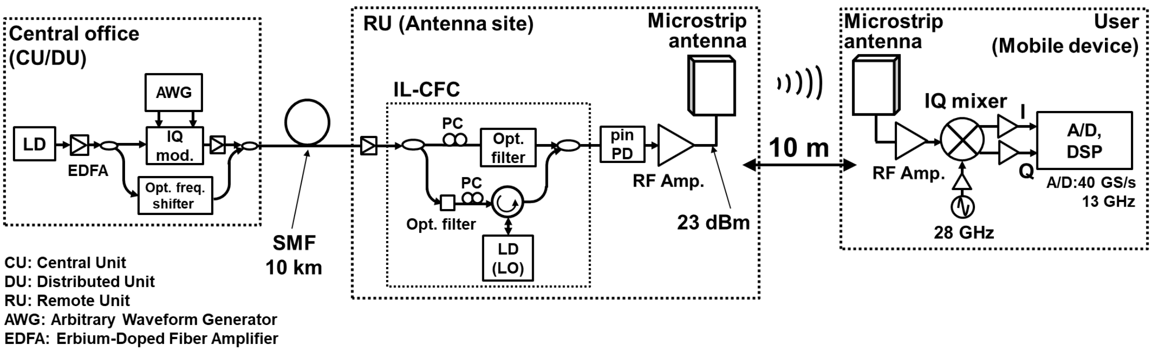


Fig. 1: Optical and wireless linked fully coherent transmission system at 28 GHz with ILCFC and small microstrip antennas.

with a linewidth of 8 kHz was IQ-modulated with 2 Gbaud, 128 and 256 QAM baseband signals, which correspond to 14 and 16 Gbit/s. The baseband signals were generated from an arbitrary waveform generator (AWG). Here, a root raised cosine filter with a roll-off factor of 0.05 was adopted to reduce the bandwidth of the QAM data to 1.05 GHz. The pattern length was 4096 symbols. By using an optical frequency shifter consisting of an LN phase modulator and an optical filter, we also generated a pilot tone (PT) signal whose frequency was down-shifted by 28 GHz from the carrier frequency. This signal was used as a seed signal for injection locking in the IL-CFC at an RU. The QAM and the PT signals were transmitted over a 10 km SMF toward the RU with a launch power of -3 dBm. The power ratio of the PT with respect to the QAM signal, P_{PT}/P_{QAM} was optimized at -13 dB.

At the RU, an LD used as an LO was injection-locked to the extracted PT signal with a phase noise of as small as 0.3 degrees. This is sufficiently small for 256 QAM demodulation. Then, the QAM signal was frequency down-converted into the 28 GHz band with a heterodyne-detection method by using the injection-locked LD. Here, a pin photodiode with a bandwidth of 75 GHz was used for heterodyne detection. The 28 GHz-IF QAM data signal was amplified and emitted from a microstrip antenna with an antenna power of 23 dBm.

Figure 2 shows photographs of the microstrip antenna used at both the RU and user site. Its specifications are shown in Table 1. This antenna comprised 8 sub-arrays, each of which consisted of 10 antenna elements. The 8 sub-arrays were all fed in-phase and the antenna gain was 19.5 dBi. The size was as small as 10 cm×7 cm and

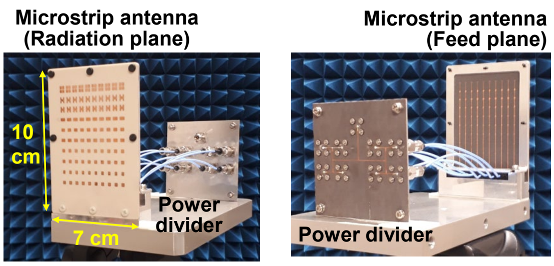


Fig. 2: Photographs of 28 GHz small microstrip antenna.

Tab. 1: Specifications of 28 GHz small microstrip antenna.

Effective bandwidth [GHz]	**27.5-29.5**
Gain [dBi]	**19.5**
Beam width [deg.]	**9 (Vertical), 13 (Horizontal)**
Size [cm]	**H10 × W7**
Fraunhofer region (Far field) [m]	**>1.4**

the vertical and horizontal 3 dB beamwidths were 9 and 13 degrees, respectively. The Fraunhofer region was over 1.4 m.

After the wireless transmission, the IF signal was amplified by using an RF amplifier with a gain of 30 dB and then converted into a baseband signal with an IQ mixer. The baseband signal was A/D converted and demodulated with a DSP. In the DSP, a finite impulse response filter was used to compensate for the waveform distortions caused by optical and electrical hardware imperfections.

Transmission results

Figure 3 shows the optical spectrum of the 2 Gbaud 256 QAM signal and the PT after a 10 km SMF transmission measured with a 0.01 nm resolution. The optical S/N (OSNR) at 0.1 nm resolution of the 256 QAM data was as high as 46.2 dB.

Figure 4 shows the electrical spectrum of a 2 Gbaud 256 QAM data signal at 28 GHz before wireless propagation. The signal-to-noise ratio (S/N) was as high as 35 dB. This high performance is attributed to the IL-CFC.

Figure 5 shows the bit error rate (BER) characteristics of 2 Gbaud 128 and 256 QAM

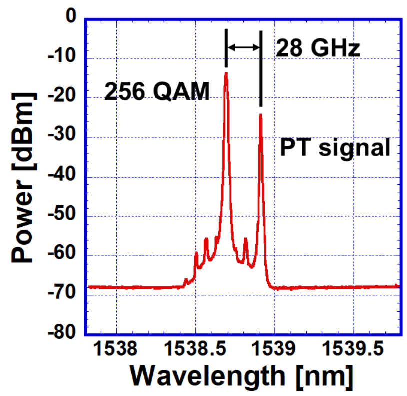


Fig. 3: Optical spectrum of a 2 Gbaud 256 QAM signal after transmission through a 10 km-SMF.

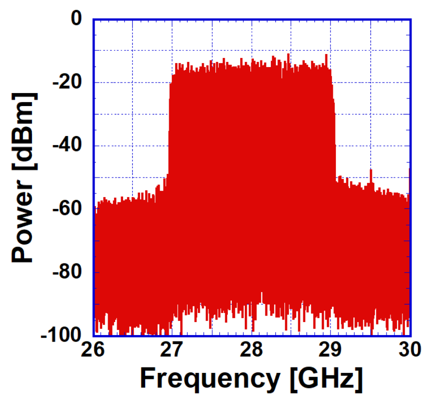


Fig. 4: Electrical spectrum of 28 GHz-IF 2 Gbaud 256 QAM data signal before wireless transmission.

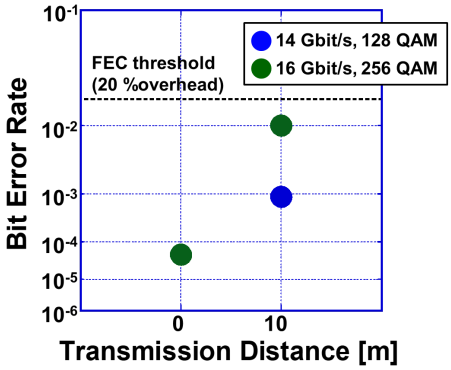
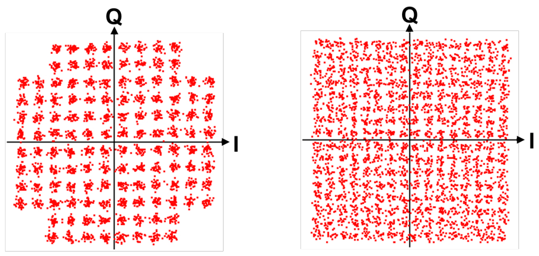


Fig. 5: BER characteristics of 2 Gbaud 128 and 256 QAM signals under a back-to-back condition and after a 10 m wireless transmission.



(a) 128 QAM, EVM:3.1 % **(b) 256 QAM, EVM:3.0 %**

Fig. 6: Constellations of 2 Gbaud, 128, and 256 QAM signals after a 10 m propagation.

signals under a wireless back-to-back condition and after 10 m wireless propagation. After 10 m propagation, the BERs of the 128 and 256 QAM signals were 8.9×10^{-4} and 1.0×10^{-3}, respectively. By adopting 20 % overhead forward error correction, error-free transmission could be achieved with all QAM signals. The free space propagation loss for 10 m wireless transmission was as high as 81.4 dB. In this transmission, the use of microstrip array antennas with an antenna gain of 19.5 dBi and RF amplifiers with a gain of 30 dB in the wireless transceiver enabled us to compensate for the free space propagation loss and to extend the wireless propagation distance to 10 m. Figure 6 shows the constellations of 128 and 256 QAM signals after 10 m propagation. The error vector magnitudes (EVMs) were 3.1 and 3.0 %, respectively. Therefore, we can say that by using small microstrip antennas and an injection locking technique, we achieved a sufficient wireless peak rate and transmission distance in terms of the application of our transmission system to beyond 5G.

Conclusions

We demonstrated an optical and wireless linked fully coherent transmission in the 28 GHz band. By using the IL-CFC and small microstrip antennas at both the RU and the user site, a 16 Gbit/s 256 QAM signal was successfully transmitted over a 10 km SMF and over 10 m wirelessly. We expect that this simple and flexible optical-wireless transmission system to provide an economical, low-latency MFH for beyond 5G.

Acknowledgements

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