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Demonstration of Coverage Extension and Blockage Mitigation with THz Relay for Indoor Network

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Abstract *We propose THz relay for indoor network and investigate its feasibility by experiment. With the THz relay, coverage extension and blockage mitigation are demonstrated with 100 Gb/s 16 QAM signal. Observed non-ideal features were discussed for future improvement. ©2022 The Author(s)*

Introduction

In order to meet rapidly growing demand of high network capacity, increase of carrier frequency is inevitable. In this respect, transmission in THz band (0.2 THz – 3 THz) has drawn significant attention [1,2]. For the THz band high-speed signal generation, photonics is expected to play a role for next generation wireless network, thanks to the matured technology in the high-speed transmission. For several years, high-speed transmission results at the THz band with the photonics-based approach have been reported with various architectures [3-6].

In order to deliver the high-speed data to the end users, indoor network also needs to support THz band transmission. However, there are two big hurdles to overcome. At first, because of its huge free space path loss (FSPL) of THz wave, the wireless coverage (i.e. transmission distance) is very limited. The FSPL can be compensated by using large-size lenses and antennas, but this approach is not desirable since the form-factor of the components is one of the most important design parameters for the indoor network. The other hurdle is that the link is vulnerable to blockage because of the high directivity. Although this vulnerability can be alleviated by beam-forming technology, capability of non-line-of-sight (NLOS) link is required for reliable transmission. Recently, reconfigurable intelligent surface (RIS) is proposed to steer beam and to cover shaded area [7]. This might be helpful, however, additional link loss by the extended transmission distance needs to compensated.

In this paper, we propose a THz relay for indoor network. Although the concept of the THz relay is proposed in previous works [8-10], our work includes the first experimental demonstration of the THz relay. In this paper, the THz relay simply consists of two antennas, one THz amplifier, and two lenses. Note that the lenses would be eliminated if the THz amplifier gain is improved. Fig. 1 shows conceptual diagrams describing the application of the THz relay. As shown in Fig. 1(a), the relay can be adopted between two access points (APs) to extends coverage. In addition, as shown in the Fig. 1(b), the relay can be combined with reconfigurable reflectors (or RIS) in order to provide capability of beamforming and NLOS link transmission. In the remaining of the paper, feasibility of the proposed THz relay is investigated by experiment. Link gain of the THz relay is measured with 60, 100, and 120 Gb/s 16 quadrature amplitude modulation (QAM) signal transmission. Then, NLOS transmission for the blockage mitigation and coverage extension are demonstrated with 2+2 m transmission of 100 Gb/s 16 QAM signal. Based on the experimental results, limitation factors are analyzed for further improvement.

Experimental setup

Fig. 2 shows experimental setup to investigate

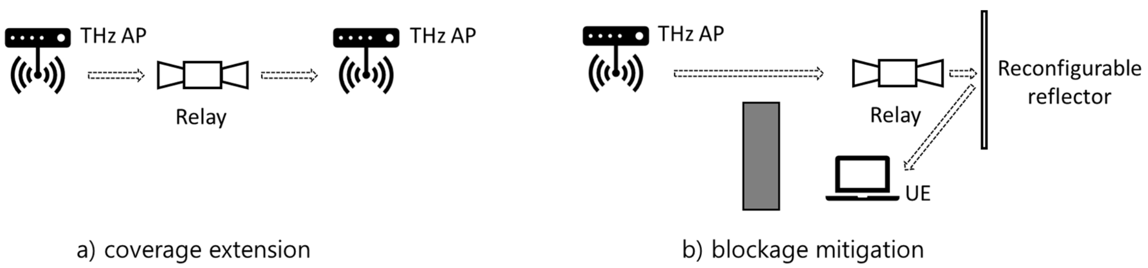

Fig. 1: Concept of (a) coverage extension and (b) blockage mitigation by using THz relay. AP: access point, UE: user equipment.

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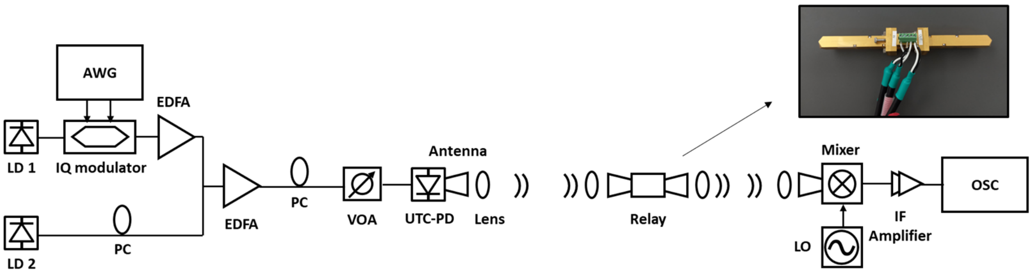

Fig. 2: Experimental setup to investigate feasibility of coverage extension. Inset shows photograph of the THz relay (without lens). LD: laser diode, AWG : arbitrary waveform generator, MZM : Mach-Zehnder modulator, PC : polarization controller, VOA : variable optical attenuator, UTC-PD : uni-traveling carrier photo diode, EDFA : erbium-doped fiber amplifier, OSC : oscilloscope.

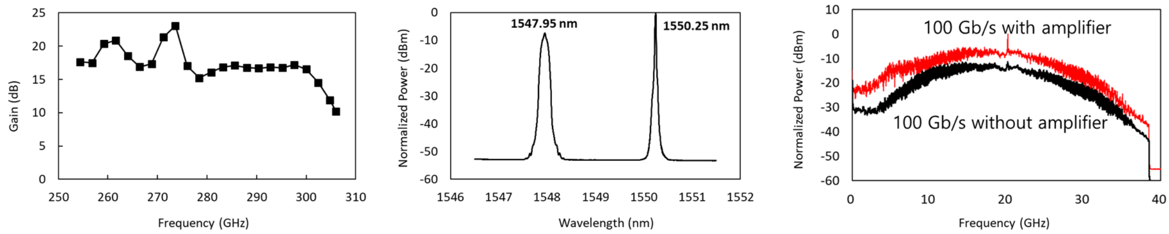

Fig. 3: (a): Gain characteristics of THz amp. (b): Optical spectrum of UTC-PD input. (c): received spectrum at the mixer.

the feasibility of the THz relay. To generate THz wave, photonics-based approach was used to take advantage in high-speed signal modulation and transmission. In this approach, output light of laser diode (LD) 1 was modulated with IQ modulator with 20 GHz bandwidth. The data was generated by arbitrary waveform generator (AWG) with 120 GS/s sampling rate and 45 GHz bandwidth. The data-carrying light is mixed with continues-wave light from the LD 2 at the uni-traveling carrier-photodiode (UTC-PD). Two polarization controllers (PCs) were used to align the polarizations. In front of UTC-PD, an erbium-doped fiber amplifier (EDFA) and a variable optical attenuator (VOA) were utilized to adjust the optical power as well as the THz Tx power. To establish wireless link, two antennas having 26 dBi directional gain and two lenses having 10 cm focal length were used. The THz relay was placed at the center of the wireless link, and the transmission distance was 1+1 m (i.e. 1 m from the THz Tx to the relay input and 1 m from the relay output to the THz Rx). Inset shows the photograph of the used THz amplifier with horn antennas. After transmission, the wireless transmitted signal was received by the mixer, and it was down-converted to intermediate frequency (IF) band. The center frequency of the IF signal was 20 GHz, which was determined by the frequency difference between the THz wave and the local oscillator (LO). The IF signal was re-amplified by IF amplifier with 55 GHz bandwidth and captured by real-time oscilloscope with 80 GS/s and 36 GHz. The captured signal was digitally processed to recover data. Details of the digital signal processing is described in our previous publication [11].

Fig. 3 describes the several characteristics of the THz relay system. Fig. 3(a) shows gain characteristics of the THz amplifier used for the THz relay. As shown in the figure, 15 – 20 dB gain was measured in 250 – 310 GHz range. Since the amplifier has flat response in 280 – 300, 288 GHz was selected as a carrier frequency after experimental optimization. The gain near the 288 GHz was ~16 dB. Fig. 3(b) shows measured optical spectrum at the input of the UTC-PD. The wavelengths were 1547.95 nm and 1550.25 nm. The optical signal-to-noise ratio (OSNR) was higher than 50 dB, thus the effect of the optical noise was negligible. Fig. 3(c) shows received spectra of 100 Gb/s 16 QAM signal measured at the oscilloscope. As shown in this figure, the distortion caused by the gain flatness was not severe. The gain by the THz relay was measured by ~ 6 dB. This 6 dB gain was 10 dB lower than the 16 dB THz amp gain in Fig. 3(a). It would be because the losses in the wireless link (e.g. insertion loss and mis-alignment loss) were included in the link gain measurement.

Link gain measurement

Fig. 4 shows BER curves with and without THz relay as a function of THz Tx power. The transmission distance was 1+1 m. Up to 120 Gb/s transmission, the measured BER satisfied soft decision forward error correction (SD-FEC) threshold (2×10^{-2}) when Tx power was properly adjusted. Thanks to the THz relay, ~5 dB link gain was measured at 60 and 100 Gb/s. This value is coincident to the measured gain shown in the Fig. 3(c) with 1 dB additional penalty. The 5 dB link

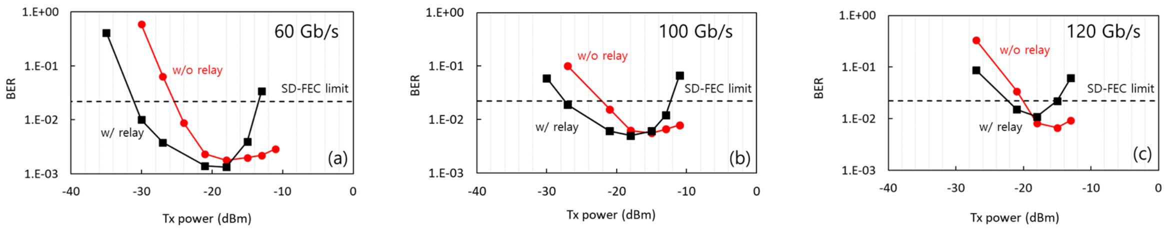

Fig. 4 : BER curves with/without THz relay as a function of Tx power at 1+1 m transmission.
(a): 60 Gb/s, (b): 100 Gb/s, (c): 120 Gb/s

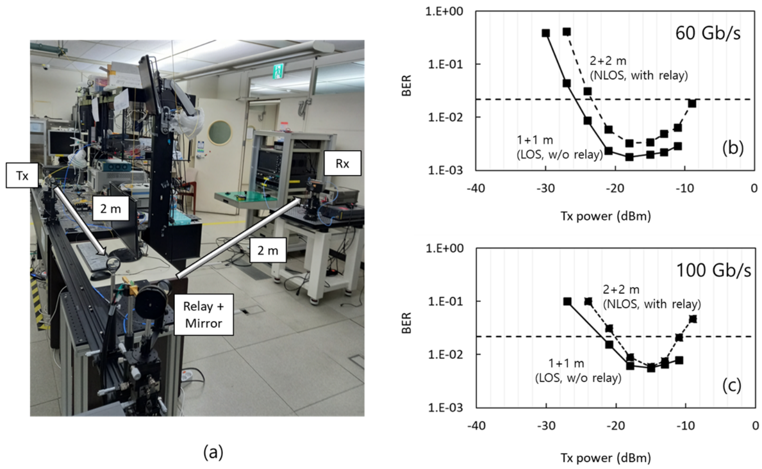

Fig. 5: demonstration of coverage extension and blockage mitigation.
(a): photograph of setup, (b): BER curves as a function of THz Tx power at 60 Gb/s, (c): at 100 Gb/s.

gain indicates the possibility of coverage extension by 1.78 times.

There were some non-ideal features which need to be improved in future. At first, with the THz relay, the BER became worse when the THz Tx power is increased at a certain level, thus dynamic range of the THz Tx power is limited. This phenomenon is due to the power saturation of the THz amplifier. To increase the dynamic range of the THz Tx power, the saturation power needs to be improved. Second, at 120 Gb/s, link gain was degraded to ~2 dB. The degradation is originated from the distortion by the non-flat response of the THz amplifier. It will be relieved if the flatness of the THz amplifier is improved.

Coverage extension and blockage mitigation

Fig. 5(a) shows a photograph of the demonstration setup. The components in the experiment were identical to the setup shown in the Fig. 2, except a mirror. The reflection angle was ~ 40 degree. The transmission distance was 2+2 m, thus it demonstrated not only the NLOS transmission for blockage mitigation but also coverage extension by twice. The transmission results for 60 and 100 Gb/s are shown in Fig. 5(b) and Fig. 5(c). As shown in these figures, the BER of 2+2 m NLOS transmission satisfied the SD-FEC threshold when THz Tx power is in the dynamic range. Comparing to the 1+1 m transmission results, the observed power penalty was ~1 dB. This is expected from the 5 dB link gain and 6 dB penalty by the doubled transmission distance.

Conclusions

In this paper, we experimentally investigated the feasibility of THz relay for THz-band indoor network. The measured link gain was 5 dB (up to 100 Gb/s), which indicates possibility of coverage extension by 1.78 times. With combining of mirror (conceptually reconfigurable reflector or RIS), coverage extension and NLOS transmission for blockage mitigation were also demonstrated. In the demonstration, 2+2 m 100 Gb/s 16 QAM was successfully transmitted satisfying SD-FEC threshold. If saturation power and flatness of the THz amplifier are improved, the transmission performances of the THz relay will be even better.

Acknowledgements

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