# Photonics-Aided Mm-Wave Communication for 5G

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**Abstract:** To meet the eMBB challenges in 5G, we have systematically explored the potential of the photonics-aided mm-wave communication in terms of the wireless transmission capacity and distance it can accommodate. Enabled by various kinds of advanced techniques and devices, we have successfully achieved the significant enhancement of the wireless transmission capacity from 100Gb/s to 400Gb/s, even to 1Tb/s, and we also have realized the record-breaking product of wireless transmission capacity and distance, i.e., 54Gb/s×2.5km.

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## 1. Introduction

Enhanced mobile broadband (eMBB) communications, as one of the three typical application scenarios of the 5G mobile communication networks, will be required to meet the demands of future ubiquitous VR/AR, 4k/8k high-definition video, artificial intelligence, and so on. Therefore, eMBB will motivate the explosive increase of mobile data traffic and rates, which requires more bandwidth at higher carrier frequencies. Mm-wave band (30GHz-300GHz) is one of the promising candidates for 5G, since it has larger available bandwidth to accommodate higher mobile data traffic and rates [1-5]. Therefore, it is interesting to explore the potential of the mm-wave band in terms of the mobile data capacity it can accommodate, and to investigate how to realize mobile data transmission within the mm-wave band at a data rate as high as possible. Photonic mm-wave generation techniques can overcome the bandwidth limitation of existing electrical components and they are more suitable for high-frequency mm-wave generation. Furthermore, photonic mm-wave generation can be seamlessly integrated with advanced vector signal modulation and DSP-based heterodyne coherent detection, to improve the spectral efficiency and receiver sensitivity of mm-wave communication systems [6-15]. The combination of multiple multi-dimensional multiplexing techniques, including MIMO-based optical polarization multiplexing, antenna polarization multiplexing, and mm-wave frequency multiplexing, can significantly increase wireless transmission capacity [16-19], while the employment of advanced devices, including high-power/large-gain electrical amplifier (EA) and large-gain small-beamwidth Cassegrain antenna (CA), can effectively extend wireless transmission distance [20-25].

In this paper, we first overview the techniques and our experimental demonstrations on photonics-aided large-capacity (>100-Gb/s) mm-wave communication. With our continuous efforts and exploration, we have successfully achieved the significant enhancement of the wireless mm-wave signal transmission capacity from 100Gb/s to 400Gb/s, even to 1Tb/s. Since our large-capacity (>100-Gb/s) experimental demonstrations typically have a very short wireless transmission distance of several meters, we have further explored the techniques for the extension of the wireless mm-wave signal transmission distance, and successfully achieved a series of field-trial demonstrations on photonics-aided long-distance (>100-m) mm-wave signal transmission. We have realized the record-breaking product of wireless transmission capacity and distance, i.e., 54Gb/s×2.5km. Our investigation and achievements verify that photonics-assisted mm-wave communication can potentially meet the eMBB challenges in 5G.

## 2. Techniques and experimental demonstrations on photonics-aided large-capacity mm-wave communication

In the photonics-aided mm-wave signal communication, by reducing signal transmission baud rate, we can loosen the bandwidth requirement for optical and electrical devices, and therefore enhance wireless transmission capacity. As shown in Fig. 1, three different kinds of approaches can be applied into the photonics-aided mm-wave signal communication to reduce signal transmission baud rate. The first kind of approaches is antenna multiplexing, which includes 2×2 antenna MIMO at the same antenna polarization, 4×4 antenna MIMO employing antenna polarization multiplexing, and 2×2 antenna MIMO employing antenna polarization diversity. Compared to antenna SISO, antenna MIMO can seamlessly integrate with optical polarization multiplexing to effectively double wireless transmission capacity [6]. 4×4 antenna MIMO employing antenna polarization multiplexing is equivalent to two 2×2 antenna MIMOs, with one at the antenna vertical-polarization (V-polarization) and the other the antenna horizontal-polarization (H-polarization). The employment of antenna polarization multiplexing can further double wireless transmission capacity, but requiring doubled optical and electrical devices [9]. The employment of antenna polarization diversity, that is, one pair of antennas at the antenna V-polarization while the other pair the antenna H-polarization, not only can effectively suppress wireless crosstalk, but also offer an easy antenna installation and adjustment [10]. The second kind of approaches is advanced high-order vector modulation, such as QPSK, 16QAM, 64QAM, and so on. The higher the modulation order, the larger the bit number per symbol and the lower the required signal baud rate [26]. But at the same time, a higher receiver sensitivity is also required with the increase of modulation order. Therefore there is a tradeoff between optimal vector modulation and overall system performance [11-15]. The last but not the least kind of approaches is mm-wave frequency multiplexing, including electrical multi-carrier modulation, optical multi-carrier modulation, and multi-band multiplexing. The simultaneously employed multiple mm-wave frequencies can be located within the same mm-wave band and also can be located at several different mm-wave bands [16-19]. The electrical multi-carrier modulation, such as electrical OFDM, is robust to fiber CD and PMD [27]. The optical multi-carrier modulation, such as optical OFDM and Nyquist WDM, gives the possibility for optical sub-carrier optimization [28]. The multi-band multiplexing can simultaneously employ several different mm-wave bands, and for example, the ultra-high-speed wireless signal can be jointly delivered by 40-, 60-, 80-, and 100-GHz mm-wave carrier frequencies at the same time.

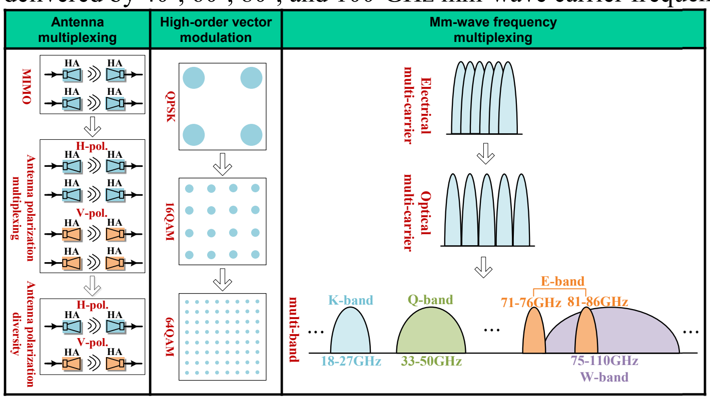


Fig. 1. Various kinds of techniques for the realization of photonics-aided large-capacity mm-wave communication.

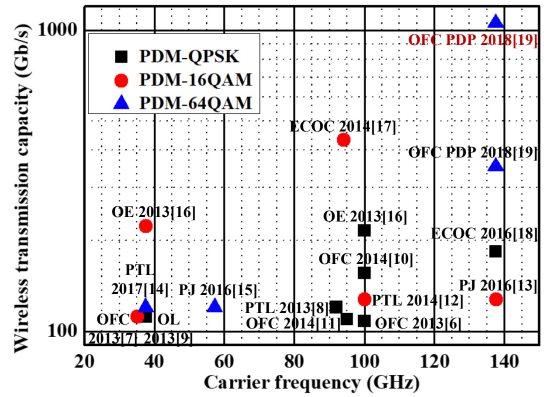


Fig. 2. Our experimental demonstrations on photonics-aided large-capacity (>100-Gb/s) mm-wave transmission.

In the past several years, we have successfully achieved a series of 100-Gb/s and beyond experimental demonstrations on photonics-aided large-capacity mm-wave signal transmission, enabled by the aforementioned various kinds of advanced techniques [6-19]. Fig. 2 summaries our large-capacity (>100-Gb/s) experimental achievements in terms of the employed mm-wave carrier frequencies, the employed high-order vector modulation, and the achieved wireless transmission capacity. We can see from Fig. 2 that our >100-Gb/s experimental demonstrations are mainly located at 40-GHz Q-band, 60-GHz V-band, 100-GHz W-band, and 140-GHz D-band. The mainly employed high-order vector modulation is QPSK, 16QAM, and 64QAM. With our continuous efforts and exploration, we have successfully achieved the significant enhancement of the wireless transmission capacity from 100Gb/s to 400Gb/s, even to 1Tb/s. We can also see from Fig. 2 that, the higher mm-wave carrier frequencies, for example, the 100-GHz W-band and 140-GHz D-band, and the higher-order vector modulation, such as 16QAM and 64QAM, are more suitable for the realization of larger wireless transmission capacity. Our record-breaking 432-Gb/s wireless transmission capacity is enabled by 100-GHz W-band and 16QAM modulation [17], while our record-breaking 1.056-Tb/s wireless transmission capacity is enabled by 140-GHz D-band and 64QAM modulation [19].

## 3. Techniques and experimental demonstrations on photonics-aided long-distance mm-wave communication

Our large-capacity (>100-Gb/s) achievements shown in Fig. 2 typically have a very short wireless transmission distance of several meters. Therefore it is interesting to further investigate how to increase the wireless transmission distance of photonics-aided mm-wave communication to hundreds of meters, while maintaining its relatively large wireless transmission capacity. Fig. 3 shows various kinds of approaches for the extension of wireless transmission distance for photonics-aided mm-wave communication. The first approach is to employ relatively low-order vector modulation, such as QPSK, 8QAM, and 16QAM. The lower the modulation order, the larger the Euclidean distance and therefore the lower the required receiver sensitivity. A relatively low receiver sensitivity requirement is advantageous to the extension of wireless transmission distance, if the wireless signal transmitting power is fixed. The second approach is to employ large-gain/high-power RF EAs. For example, the commercially available W-band low-noise amplifier (LNA) can have a large gain of ~25dB within the whole W-band, while the commercially available W-band power amplifier (PA) can have a high output power of over 20dBm within the frequency range from 77GHz to 100GHz. We have experimentally demonstrated that when we add the large-gain LNA and high-power PA into our wireless transmitter/receiver ends, the wireless transmission distance at W-band can be significantly extended [21]. The third approach is to employ heterodyne coherent detection combined with DSP. Compared to homodyne coherent detection, simplified heterodyne coherent detection is much more hardware-efficient and suitable for system integration [29]. Moreover, the state-of-the-art receiver-based DSP algorithms can effectively improve receiver sensitivity and system performance [30], and therefore promote the extension of wireless transmission distance. The fourth approach is to employ antenna polarization diversity. Wireless crosstalk may occur in antenna MIMO, and can become more severe with the increase of wireless transmission distance, which makes the proper adjustment of receiver antennas difficult for long-distance wireless mm-wave transmission. As mentioned in Section 2, antenna polarization diversity can effectively suppress wireless crosstalk and offers an easy antenna installation and adjustment. Thus, the employment of antenna polarization diversity can effectively promote the extension of wireless transmission distance. The last but not the least approach is to employ the CAs. Compared to typical horn antenna (HA), CA has a large gain and a small half-power beamwidth at the cost of a large size and a heavy weight. Therefore, the wireless transmission distance can be extended from several meters with HAs to several kilometers with CAs.

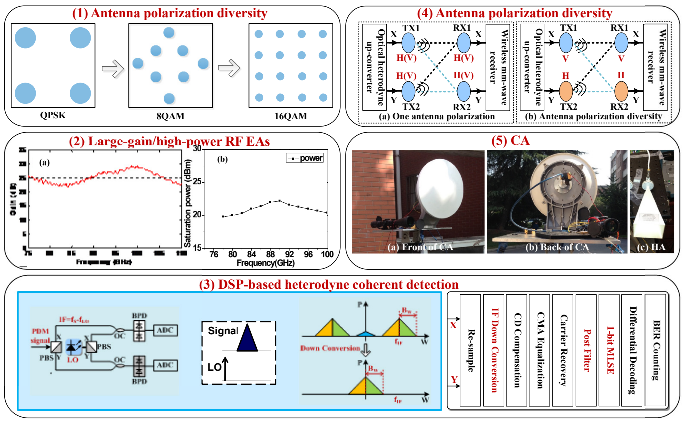


Fig. 3. Various kinds of approaches for the extension of wireless transmission distance for photonics-aided mm-wave communication.

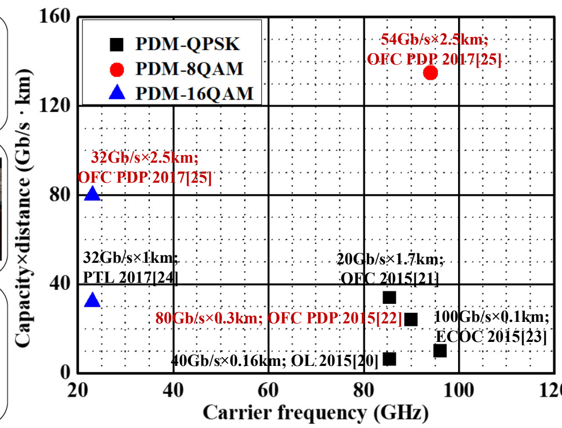


Fig. 4. Our experimental demonstrations on photonics-aided long-distance (>100-m) mm-wave transmission.

In the past few years, enabled by the aforementioned various kinds of techniques, we have successfully achieved a series of field-trial demonstrations on photonics-aided long-distance (>100-m) mm-wave signal transmission [20-25], as shown in Fig. 4. All our field-trial demonstrations are carried out under a good weather and LOS transmission. We can see from Fig. 4 that our field-trial demonstrations are mainly located at 20-GHz K-band and 90-GHz W-band, since these two bands have relatively low atmospheric loss. The mainly employed vector modulation is relatively low-order QPSK, 8QAM, and 16QAM. The largest product of wireless transmission capacity and distance, i.e., 54Gb/s×2.5km, has been achieved at 90-GHz W-band with 8QAM modulation.

## 4. Conclusions

Enabled by photonics-aided mm-wave generation technique, multiple multi-dimensional multiplexing techniques, and state-of-the-art devices, we have achieved the record-breaking wireless transmission capacity up to 1Tb/s as well as the record-breaking product of wireless transmission capacity and distance up to 54Gb/s×2.5km. Our investigation and achievements will form the basis for the development, standardization and final implementation of photonics-aided mm-wave communication systems to meet the eMBB challenges in 5G.


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